Put them on the map!

Optimising cetacean conservation management in Indonesia through governance refinement and habitat-use-based spatial planning using complementary methods and underused data

Achmad Sahri

Propositions

1. Habitat-use-based spatial planning is imperative for cetacean conservation optimisation.
   (this thesis).
2. Although enforcement is more challenging, ecological boundaries are more functional in marine spatial planning than administrative boundaries.
   (this thesis).
3. For every ten scientists in the field at least one is needed behind a computer screen.
4. Data sharing restrictions limit research.
5. Imperialism and colonialism are manifestations of human 'invasive species’ events.
6. The most sustainable way of reducing human pressure to environment is birth control.

Propositions belonging to the thesis, entitled:

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Optimising cetacean conservation management in Indonesia through governance refinement and habitat-use-based spatial planning using complementary methods and underused data.

Achmad Sahri

Wageningen, 6 April 2021

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This research was conducted under the auspices of the Graduate School WIAS (Wageningen Institute of Animal Sciences)

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Achmad Sahri

Thesis
submitted in fulfilment of the requirements for the degree of doctor
at Wageningen University
by the authority of the Rector Magnificus,
Prof. Dr A.P.J. Mol,
in the presence of the
Thesis Committee appointed by the Academic Board
to be defended in public
on Tuesday 6 April 2021
at 11:00 a.m. in the Aula

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Put them on the map!
Optimising cetacean conservation management in Indonesia through governance refinement and habitat-use-based spatial planning using complementary methods and underused data
250 pages

PhD thesis, Wageningen University, Wageningen, The Netherlands (2021)
With references, with summary in English
ISBN: 978-94-6395-698-7
DOI: https://doi.org/10.18174/541076

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" ... allowing them (*cetaceans*) the freedom to roam free in the ocean is not enough. ... (*they*) have a fundamental right to healthy habitat."

Erich Hoyt

Chapter 1

General Introduction

It is a commonplace today that many cetacean species are threatened due to mainly anthropogenic factors. Although officially protected by international treaties and national regulations, in reality, these animals are threatened by many aspects they are officially protected from. Not only because they suffer from direct and indirect effects such as bycatch and prey species depletion or because regulations may not be enforced, but also because their critical habitats and migration corridors are hardly considered in conservation management. Cetaceans have inherent value as species, because people consider them ‘charismatic’, and for the significant roles they play within ecosystems [1]. As important apex predators of the marine food chain, they play a critical role in regulating lower trophic levels thus supporting resilience of ecosystems [2–5]. Depletion of cetaceans can therefore has cascading effects on lower trophic levels [6,7]. As umbrella species, protecting cetaceans through marine reserves would result in the protection of several other species in these ecosystems, thus protecting a wider range of biodiversity [4,8–10]. As sentinel species, they can be used as a barometer for evaluating ecosystem health [11]. As flagship species, they represent public interest and powerful political goals for the conservation of less known species or habitats [1,12].

For effective conservation management, the ecology and status of cetaceans and their habitat must be known [13–16]. Information such as population distribution patterns and habitat use is crucial in the process of designating area-based management tools such as marine spatial planning (MSP) and marine protected areas (MPAs) [12,17–19]. With such management tools, critical habitats of the target species can be protected, including key areas for feeding, breeding and calving as well as areas important for socializing, nursing and resting and not to forget the core migration routes between them [1]. As migratory species, cetaceans typically forage over wide areas of ocean, but often also aggregate in smaller and localised areas (called ‘hotspots’) for certain periods of time [12]. Identifying cetacean key areas and environmental characteristics determining these areas for conservation planning and management are the essence of this thesis.

All anthropogenic and ecological marine uses have a spatial component, and area-based management tools such as MSP and MPAs [20] aims to optimise marine space use by balancing species ecological needs and human activities. Habitat-use-based spatial planning is a relatively emerging field in area- and ecosystem-based management, however until now this has been hardly applied for migratory species [1]. For instance, many MPA and MSP establishments in Indonesia used a speculative approach rather than a scientific-guided approach in incorporating critical habitats and migratory routes of marine mobile species; a matter that, on the other hand, is mandated by its national regulations (Box 1.1). Different from a precautionary approach [21] that tends to make a conservative decision in the absence of scientific information (e.g., put the migratory corridors as a large area within MPA or MSP), the speculative approach only drawing corridors as indicative lines for the sake of fulfilling the obligation from regulations, although in fact they may not represent the real corridors used by the migratory species. To strengthen this weakest link, an approach should be developed to be able to include the habitat use in the spatial planning.

Box 1.1. Indonesian regulations that mention protection of habitats and migration corridors

Although the following regulations do not explicitly state the protection of cetaceans, they highlight the importance of migration corridors and habitat protection during the establishment of marine protected areas (MPAs) or similar systems and marine spatial planning (MSP).

Law 31/2004 and its derivative Government Regulation No. 60/2007 art. 6 and 9 state that stipulation of aquatic conservation areas have to take ecological aspects into account including habitats and migration corridors of marine biota.

Law No. 27/2007 art. 28 (amended by Law No. 1/2014) mandates the protection of migration corridors and habitats of marine biota in developing a zoning plan for the coastal areas and small islands (called RZWP3K or provincial MSP) from coastlines up to 12 nm seaward.

Ministry of Marine Affairs and Fisheries (MMAF) Regulation No. 16/2008 art. 15 (amended by MMAF Regulation No. 34/2014) mentions that a migration pathway of marine biota is one of the sea lanes that should be incorporated in RZWP3K.

MMAF Regulation No. 17/2008 art. 6 and 32 state that the core zone must be defined in the designation of coastal and small island conservation areas, and include habitats and migratory corridors of marine biota.

MMAF Regulation No. 2/2009 art. 4, 5, 8, and 15 and MMAF Regulation No. 30/2010 art. 7, 10, 14, 18 and 19 emphasise the importance of habitats and migratory corridors in the stipulation of aquatic conservation areas.

Law No. 32/2014 on the explanation of art. 43 mandates the government to protect the marine environment and migratory species through marine conservation in the territorial and high seas.

In this Introduction, I first describe the ecology of cetaceans, the status of cetacean conservation in Indonesia, followed by the description of area-based management tools. I then review existing knowledge, the methodological approaches and datasets used in the thesis, and summarising the knowledge gaps. Finally, I provide the aim and research questions of the study, outline of the thesis, and the links between the chapters.

1.1. Cetacean traits and related threats

Cetaceans are the majority group of marine mammals and include a diverse array of species that are divided in three main groups: whales, dolphins, and porpoises. Two major groups of cetaceans are recognised: the Mysticetes, or baleen whales, and the Odontocetes, or toothed whales [22,23]. All dolphins and porpoises belong to the latter group. Odontocetes are more diverse, comprise of approximately 75 known species compared to only 14 Mysticete species [22].

Each species of cetaceans is adapted to specific habitats with geographical distributions from tropical to polar regions, shallow to deep waters, estuarine to marine regions, and everything in between [22]. Biotic (mainly prey abundance) and abiotic factors (e.g., temperature, ocean currents and submarine topography) determine cetacean distribution [22]. Some species aggregate in distinct geographical areas year-round or perform limited movements (mainly small odontocetes), some others (such as baleen whales) are more cosmopolitan with seasonal ocean-basin migrations [24,25]. The key drivers for the migrations depend on life cycle stages and sex and typically are related to the availability of food, presence of mates, and shelter from predators [26–28]. The depletion in whale stocks in the early 1900s triggered the beginning of the scientific study of cetacean and marine mammals in general, with the aim of such studies was mainly to obtain accurate biological and ecological information for sustainable exploitation [23]. Historical intensive exploitation may have led to a shifting baseline in species densities. Areas that currently are considered to be abundant in cetaceans, probably only represent a fragment of former densities that used to occur there [29].

Most of cetacean species populations do not easily recover after perturbations due to their life-history traits with relatively slow growth, long parental dependence, late maturity, low reproductive rate [30–32]. Unfortunately, with their large range migration, cetaceans encounter many risks, and with their long-life span, they are susceptible to chronic threats such as toxic compound accumulation [33,34].

There has been a long history of humans having adverse impacts on cetaceans, starting with historical and commercial whaling which led to many population declines. Currently many anthropogenic threats are added to this, such as habitat degradation and loss [35–37], consequences of fisheries (entanglement, bycatch, prey depletion) [38–42], collisions and acoustic disturbance by marine traffic [43–45], seismic disturbance from oil-gas exploration and naval sonar [46,47], chemical pollution (spilled oil, heavy metals, persistent organic pollutants), marine plastic pollution [33,34,48–51], and pathogens such as morbillivirus [52]. Unfortunately, in some places, cetaceans even still are a target of illegal fishing for human consumptions and for fishing baits or they are killed to reduce competition for fishery resources [12,53–55]. New threats also have been emerged, including coastal and offshore development, extensive offshore energy production, intrusive whale watching tourism, marine resource extraction, and climate change e.g., for ice related species [56–58]. All these direct and indirect pressures together maybe be hard for cetaceans to cope with, and several species currently are under serious threat and may even go extinct if not managed properly soon [59].

Nowadays, most of the cetacean species are legally protected under several global directives and national laws in most countries, which makes the development of associated conservation management and legislative measures a priority [60]. The

International Union for the Conservation of Nature (IUCN), for instance, has categorised most species of whales and dolphins as Red List species, although the species differ in status from Data Deficient, Least Concern, Vulnerable to Endangered [61–64]. Furthermore, the Convention on International Trade in Endangered Species of Wild Flora and Fauna (CITES) listed most of marine mammal species in its Appendices I and II [65,66], requiring extreme control of animal trading to avoid extinction. Additionally, the United Nation Convention on Law of the Sea (UNCLOS 1982) explicitly stresses the importance of marine mammal conservation for all ratifying countries [67]. Although officially most of the cetacean species are protected by above mentioned treaties, in practice they are not, because their critical habitats and migration routes are hardly considered and mostly even unknown (Fig. 1.1). In addition, the international treaties are burdensome to enforce, since governance at this level is carried out by means of voluntary international agreements, and it depends on ratifying states to take decisive actions [1].

1.2. Cetacean conservation situation in Indonesia

The Indonesian archipelago is located at the centre of the Coral Triangle region, therefore has exceptional tropical marine biodiversity. Regional scale studies have identified the region as the most biodiverse marine area in the world and therefore are designated as a global priority for marine conservation [68–71]. Huffard et al. [72] have confirmed the importance of Indonesia within the region as a favourable habitat for many cetacean species. The Indonesian waters are situated in an upwelling system, where wind regimes and oceanic currents strongly influence the temperature and primary productivity [73,74], benefiting marine species at all levels of the food web, including cetaceans [72]. Substantial reductions in populations of top predators such as cetaceans have led to a shifting in main predator domination and eventually food web nuisance [6]. The area is characterised by warm waters year-round from the Indonesian Through flow [75]. The area, especially deeper eastern waters of the country has a diverse and complex submerged topography with inter-island channels in the eastern part serve as passages for migrating marine mammals [76]. Therefore, Indonesia is home to a high diversity of cetacean species [53] which are a key megafauna group of the country's marine ecosystems. At least 34 species of whales and dolphins occur in Indonesia [53,77], which account for 37% of the total of 89 species of known cetaceans [22]. This demonstrates that Indonesian waters are important for cetaceans and provide the potential for developing cetacean-based ecotourism. The region was a popular whaling ground for large whales during Yankee whaling era from 18th to early 20th century [78]. Within Indonesia, several eco-regions and seascapes, such as the Bird's Head Seascape in Papua, the Banda Sea and Lesser Sunda ecoregions, are among the top priority conservation areas, especially because

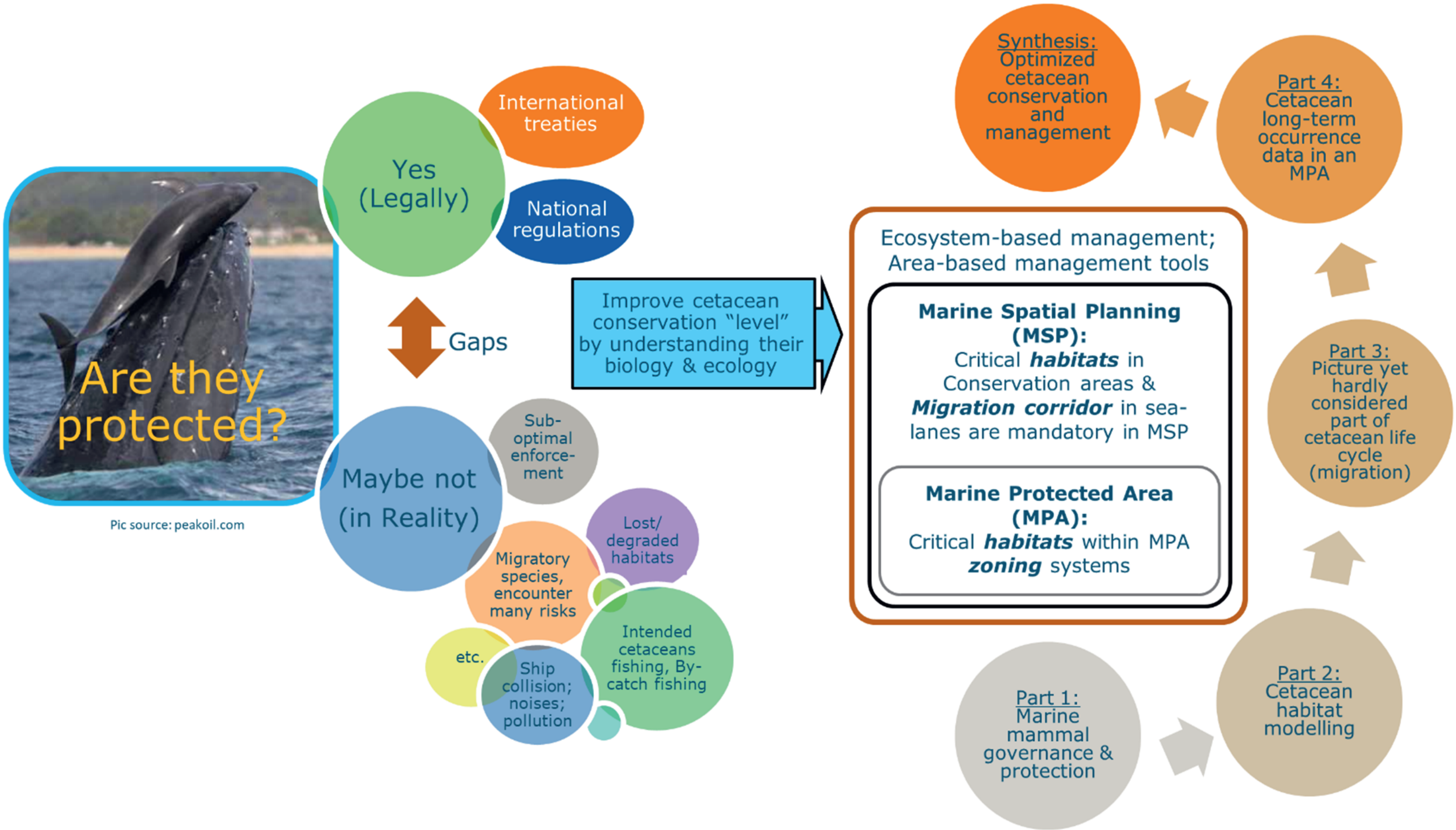

Fig. 1.1. The conceptual framework of the PhD thesis "Optimising cetacean conservation management in Indonesia through governance refinement and habitat-use-based spatial planning using complementary methods and underused data". The left panel depicts the background of the thesis, and the right panel is a proposed stepwise approach to advance cetacean conservation management in Indonesia.

of cetacean presence [69,72]. However, the cetacean occurrence is hardly studied, particularly in remote areas. Improving our understanding of the spatial distribution and ecology of cetaceans is very important for Indonesia, as several cetacean populations of conservation concern coexist with intense anthropogenic pressure on the marine environment.

The Indonesian government has committed to improve the actual conservation level of marine mammal species, mainly by stipulating relevant regulations and establishing area-based management tools such as MPAs and MSP [12,79]. The marine mammal governance in Indonesia started to come of age in 1972 when a regulation was issued as a legal basis for the protection of dugong, then dolphins and whales in the subsequent years. In this phase, regulations were mainly issued to protect individual species. From 1990 onward, the regulations reflected area-based management approach mainly by stipulating regulations for MPAs or other similar systems. From 2010 onward, it is characterised by a wider marine management approach including zoning of activities and protected areas by MSP and fisheries management.

Indonesia also showed high commitment and is always open to global initiatives in marine mammal conservation and marine management in general. Since 1978, Indonesia has ratified the CITES convention that emphasises a marine mammal protection approach through strictly managing global commercial trade of all threatened and endangered species. Indonesia also ratified the UNCLOS treaty in 1985 that regarding marine mammal management, explicitly encourages international cooperation on species conservation among ratifying countries. In 1994, Indonesia ratified the Convention on Biological Diversity of the United Nations (CBD) that is the parent multilateral treaty on conservation of biodiversity and the sustainable use of its components. Indonesia has also been actively involved within regional initiatives where marine mammal management are attached within their wider marine management agenda. This includes the country's involvement in the Coral Triangle Initiative (CTI) that, among others, aims to improve the status of threatened species, including marine mammals [80], and its involvement in marine biodiversity programs within the Association of Southeast Asian Nations (ASEAN) [81].

Identifying key cetacean habitats in Indonesia is required by the National Plan of Action for Cetaceans [53] and under the Regional Plan of Action for Coral Triangle Initiative [80], as well as a legal duty specified by national legislations [82]. All these documents ask for a better understanding of the biology and ecology of cetacean species for conservation purposes including investigating cetacean population, identifying migratory routes and critical habitats [53]. A same query also asserted by the 2002-2010 IUCN Conservation Action Plan for the World's Cetaceans [32].

More recently, the marine mammal management in Indonesia was advanced by regulations demanding that critical habitats and migration routes of marine biota have to be incorporated in MSP through a zoning plan for coastal areas and small islands from coastlines up to 12 nm seaward (Box 1.1). The regulations also introduced a shift from marine management at district levels to provincial levels. As a result, a number of MSPs were re-designated [83]. This national guidance, however, is implemented differently with several provinces have no migration corridors in their MSPs. Ocean zoning within national jurisdiction waters, EEZ and high seas is also emphasised by the regulations mandating the government to protect migratory species through marine conservation in those seas. However, among the 177 MPAs in Indonesia, only two have been formally designated for cetaceans [84], while there clearly is an urgency to incorporate cetacean key areas in area-based management tools such as MPAs and MSP. Of course, this is only possible when information on cetacean habitat requirements, migration corridors and threats becomes available.

1.3. Area-based approaches for cetacean conservation management

An area-based management tool is an approach that allows the application of management measures to a certain area to attain a desired policy outcome [85]. The area-based management tool is a strategy within wider ecosystem-based management (EBM) concept (Fig. 1.1). To be able to adopt the EBM concept, the best available scientific knowledge about the ecosystem has to be applied and the approach adapted when relevant new information becomes available [1]. This makes our study that attempts to adopt cetacean's critical habitats and migration corridors in area-based management tools in Indonesia that has previously been overlooked finds its relevance (Fig. 1.1). Various area-based management tools exist, each with their own purpose, mandate and authority [85]. Two most popular tools are MSP and MPAs [86], elaborated below.

Marine Spatial Planning (MSP)

To protect cetacean key areas, area-based management tools are very important, especially MSP. It is a powerful tool in sustainable marine ecosystem management [87,88]. The UNESCO defines MSP as "a public process of analysing and allocating the spatial and temporal distribution of human activities in marine areas to achieve ecological, economic, and social objectives that are usually specified through a political process [89,90]." MSP is a cross-sectoral approach that applies ecosystem-based sea use management, and as such, it is relevant for many aims, e.g., prevent fish stock depletion or identify synergies and conflicts between different uses [87,89,91,92]. The additional benefits of MSP include a more rational site selection for development and conservation, more efficient use of marine resources, and a more strategic and proactive framework for decision making than conventional approaches [93]. MSP is an important tool to minimise negative impacts of marine natural resources usage on vulnerable species by providing spatial protection from direct and indirect anthropogenic threats [94,95]. For large migratory species such as cetaceans, MSP is recognised as an imperative measure, since they encounter many risks for which spatial considerations are relevant [1,12]. Crucial as basis for MSP is mapping the spatial distribution of key ecological processes and biological features [96,97]. In this context, understanding the spatial extent of species distribution, their hotspots, and their main stressors thus is a crucial step in MSP processes to protect cetaceans and develop future, more species-relevant MSP.

Indonesia is adopting an MSP approach to address conflicting objectives of human usage, resource development and conservation in marine spaces. A legal framework for the development of MSP in Indonesia has been initiated under its national regulations (Box 1.1). There is a provision for the development of zoning plan for the coastal areas and small islands from coastlines up to 12 nm seaward. Before 2014, the mandate to develop the zoning plan was in district government levels, but after marine management shifting in that year, the zoning plan development belongs to provincial governments' responsibility afterward. The provision for ocean zoning in territorial, EEZ and high seas is also mandated by national regulation (Box 1.1). Migratory species such as cetaceans have a special attention within those regulations, because the critical habitats and migratory species of these marine biota should be included within MSP and MPA establishment. The protection management for top predators such as cetaceans is highly efficient, leading to higher biodiversity and more ecosystem benefits [8]. Therefore, protecting cetacean habitats should be a priority issue for MSP development as their protection could act as indirect measures for ocean management in general [4,98].

Marine Protected Areas (MPAs)

A specific and essential instrument within an area-based management approach and in MSP is the designation of MPAs. The IUCN defines MPA as "a clearly defined geographical space, recognised, dedicated and managed, through legal or other effective means, to achieve the long-term conservation of nature with associated ecosystem services and cultural values [99]." Like with MSP, MPAs are gaining momentum in marine conservation because they can serve different goals simultaneously. Various studies have examined possible synergies such as between nature conservation and tourism [100,101], nature conservation and fisheries management [102,103], and nature conservation and scientific research [104]. The term "protected" is used differently and is principally determined by the goal set for such areas, e.g., nature conservation, fisheries management, tourism, or others.

Although MPAs are widely recognised as a key tool in marine biodiversity conservation [105–107], their effectiveness in conserving migratory species is doubtful [98,108]. It is unknown to what extent MPAs cover the migratory species habitats [109], because the population distributions are understudied. The extent of protection also vary depends on the types of MPAs, with relatively large IUCN-category-I MPAs tend to provide adequate protection for specific focal species [1,109,110]. MPAs that are primarily designed for protecting sessile species or limited migratory species may have little benefits in protecting highly mobile species [111,112]. The different extent of species movement making the identification of MPA boundaries a challenge [18]. Of course, an adequate management regime (including enforcement) also determines the degree of MPA protection and effectiveness [58,113].

A number of MPAs have been established in Indonesia, and to date >20 million hectares of the marine environment in Indonesia's jurisdiction is legally under some kind of protection [84]. This is the fulfilment of the government's commitment as declared during the Conference of the Parties of the Convention on Biological Diversity (COP-CBD) in 2006 and during the World Ocean Conference in 2009 [114]. The types of MPAs in Indonesia vary from relatively wide marine national parks to smaller marine conservation areas managed together with local communities. These all concurrently will contribute to an ecologically coherent network of MPAs. Although some of the MPAs have cetacean habitats, only two were officially designated for cetaceans [84] and critical habitats and migration corridors of cetaceans are not yet known, so are not yet included in MPAs and MSP in Indonesia.

1.3.1. Habitat-use-based spatial planning

The term 'habitat' is a nucleus concept when discussing wildlife management and species distribution, but nevertheless remains ambiguous [115]. In this thesis, I use habitat definition as "the area occupied by the species, which has specific environmental conditions required for the survival of a species". With this definition, home range, migration corridors, and core-use areas are a part of habitat. Habitat use often vary depending on different requirements for specific life cycle traits of a species [116,117].

Habitat-use-based spatial planning is an aspect of ecosystem-based spatial planning, and both are based on the best available ecological knowledge. The wider ecosystem-based spatial planning, however, usually includes multiple species/taxa in conjunction with non-living components and multiple human uses, where habitat-use-based spatial planning focusses on a guild of species in similar taxa (in this case, cetaceans). In practical terms, habitat-use-based spatial planning is a planning process that incorporates key habitats of target species (in this case, cetaceans) in area-based management tools such as MSP and MPAs. Such spatial planning for cetaceans, however, together with spatial ecology information (home range, migratory corridors, and seasonal habitat use) are still lacking in Indonesia.

1.3.2. The need for an integrated approach

Many establishments of area-based management tools such as MSP and MPAs have been recognised sector-wise, although for a good ecosystem-based management, a more integrated approach is necessary. The management is not one sector alone, but rather is in conjunction with a suite of other management mechanisms in order to achieve the desired goals of the management plan. Such an approach, for instance, would take not only human activities into account, but also the spatial ecological needs of migratory species in MSP and MPA establishments. The need for spatial considerations of critical habitats and migratory corridors of marine biota as an integral part of MSP and MPAs is mandated by the Indonesian regulations (Box 1.1), however this notion still has less concern. Accounting for all possible uses is imperative, because ignoring one use can undo all positive gains from another. A systematic conservation planning process [118] should incorporate all possible uses during the designation process. Thus, it is crucial that activities in the marine domain including nature conservation and human activities are considered simultaneously. This implies that the sectoral approach should be replaced with a more holistic and integral area-based management approach.

The integrated approach implies also to utilise all available information currently available as inputs [17,87], from the entire planning area to avoid biasing prioritisations towards areas where data exist. This includes applying historical and multi-source non-systematic data as alternatives in poor-data availability situations. In many places, the designation of MSP and MPAs has been largely driven by socio-political interests rather than ecological considerations [e.g., 119]. As a result, the ability of such area-based management tools to protect marine biodiversity from anthropogenic threats is uncertain. In this regard, adopting a habitat-use approach for integrated spatial planning is necessary.

1.4. Identifying key governance aspects and conservation hotspots using multi-method approaches and available datasets

To identify key governance aspects of marine mammals, policy and governance analysis is needed. To be able to identify conservation hotspots, several types of habitat models and available datasets can be applied. The overview of the methods and datasets elaborated as follows (see Fig. 1.2).

1.4.1. Policy and governance analysis

The governance quality of marine conservation initiatives has triggered longstanding debates and serious critique [120], particularly regarding their ability to provide real protection to target animals. Designing and regulating protection of mobile marine species is challenging, particularly because they are far ranging species [121]. The implementation of policies, the enforcement and effectiveness of the policy

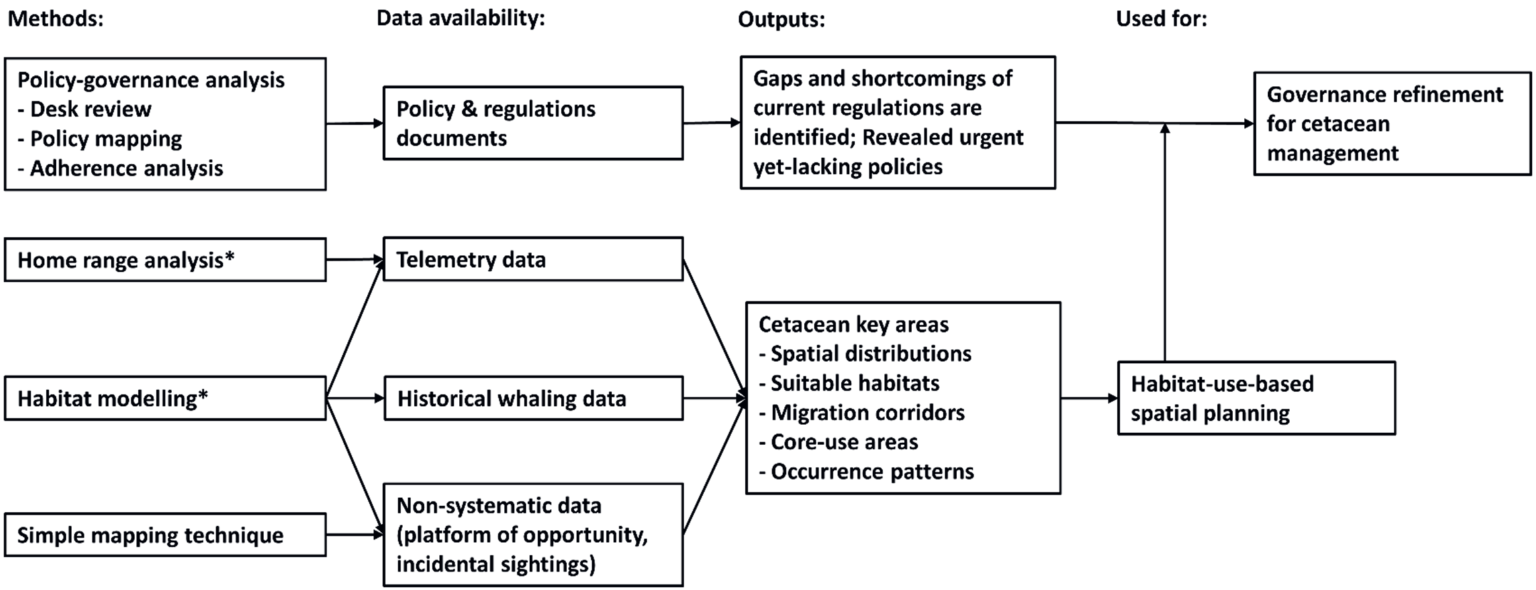

Fig. 1.2. Overview of the methods and data used in this PhD thesis and the outputs that can be used in habitat-use-based spatial planning to support cetacean management. *Detailed method overview on home range analysis and habitat modelling can be seen in Fig 1.3 and 1.4.

measures has also been remained questioned for decades [122], and the governance of marine mammal conservation in Indonesia is not an exception. A better understanding of the strengths, weaknesses, gaps and overlaps within the current legal framework, hence is imperative to improve governance aspects; a domain of policy and governance analysis.

To be able to informing effective management policy, firstly detailed information about the species ecology is needed [123]. This is usually gathered from research papers that are not aimed at answering policy needs and therefore not easily applicable [124]. Bridging the gap between science and policy for migratory species like cetaceans is a crucial first step in translating the ecological knowledge into policy [125]. One of the options is using reported observations for identifying cetacean spatial distribution and their key areas.

1.4.2. Types of spatial distribution and habitat models

To be able to identify spatial distribution and areas important for cetaceans, several methods are at hand including home range analysis, complex habitat modelling, as well as a simple mapping technique. This is elaborated in the following paragraphs. The applicability of the various methods depends mainly on the research objectives and data availability [126].

Home range analysis

When animal's movements are tracked, a so-called home range can be assessed by converting the tracked movements into a spatial representation of the range in which an animal occurs [127]. Home range analysis is used to generate expected movement trajectories of modelled animals and thereby home ranges, migration corridors, and core-use areas can be estimated [128,129]. The output of such analysis summarises the area and relative intensity of use [130]. Several statistical models exist to construct a home range and migration corridors (Fig. 1.3, Box 1.2) and they all come with specific advantages and limitations [131] that are important to consider to prevent incorrect conclusions about the occurrence of a species. Home ranges can be used to reveal the distribution and abundance of a population [132], habitat selection [133], predator-prey dynamics [134], and can aid to assess the efficacy of the area-based management tools (MSP and MPAs) [8,108].

Ecological niche/species distribution/habitat modelling

Different methods to predict species distribution and habitat suitability are developed (Fig. 1.4) and come in several names: species distribution models (SDMs, most frequently used), ecological niche models (ENMs), bioclimatic envelope models, resource selection functions, or simply habitat modelling [146]. Such models predict the potential distribution of a species based on statistical relationships between recorded occurrences and environmental variables [147,148]. Habitat models do this by identifying environmental characteristics that influence known distributions of a species and finding other areas that share these characteristics [147,148]. The "niche" concept is a principal element in the process of habitat modelling (see Sillero [149] for details).

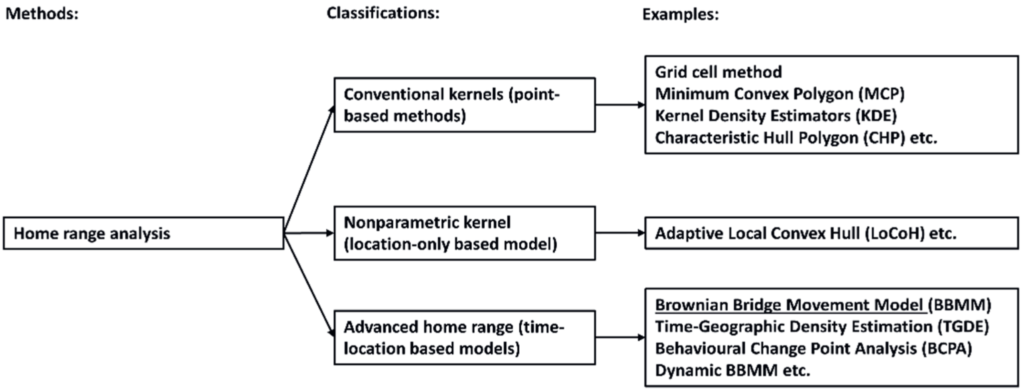

Fig. 1.3. Overview of methods for cetacean home range analysis. For home range analysis, telemetry data are needed. Based on research objectives, only the Brownian Bridge Movement Model (BBMM) was used in this thesis.

Box 1.2. Methods for home range analysis

Home ranges constructed directly from the points are the most ancient, simple and frequently used methods. Examples of such methods are the grid cell method [135], Minimum Convex Polygon (MCP) [136,137], Kernel Density Estimators (KDE) [130] and Characteristic Hull Polygon (CHP) [138]. Problems with these conventional methods are regarding over- or underestimation the size of the home range or failing to identify high and low use areas [139]. Newer nonparametric kernel methods such as adaptive Local Convex Hull (LoCoH) [140] are able to overcome some of the problems by adapting the involvement of the number of points depending on the density of points and are also able to exclude non-usable areas. However, this method remained tends to underestimate home ranges [141]. In addition, most methods need regular interval tracking data or temporally independent location data [142]. Abovementioned methods are mainly location-only based models that are less suitable for migrating animals [116,129]. To overcome the issue with irregularity of the tracking data, the independence assumption and inability to accommodate time-location data, there are several methods developed: the Brownian Bridge Movement Model (BBMM) [129], Time-Geographic Density Estimation (TGDE) [143] and Behavioural Change Point Analysis (BCPA) [144]. Additional to the BBMM is a dynamic BBMM that provides a supplementary measure of behavioural change along animal tracks [145].

Habitat modelling allows finer spatial predictions of cetacean densities than fragmented point visualisations or traditional abundance estimates, because cetacean densities are estimated as a continuous direct and indirect function of habitat variables (e.g., sea surface temperature, bathymetry) [150,151]. For practical reasons also, e.g., to assess the overlap between species habitats and marine reserves, it is easier to overlay cetacean distribution in the form of area (polygon) instead of fragmented points. Therefore, in this context and to provide a better assessment of the full distribution of species, habitat modelling is crucial to be applied.

Several classifications of habitat models exist (Fig. 1.4, Box 1.3). It is recommended to compare different model outputs to assess the model similarities and variance [152,153]. There is also a need to provide estimates of error or uncertainty of the models [154], because if management planning is based on a model without taking this into account, counterproductive effects could be introduced [153]. The use of different models makes it possible to compare and evaluate their abilities and outputs, thereby scientifically determine which models describe the distribution and habitat preferences of species with the greatest confidence.

Habitat modelling are now largely used not only for theoretical studies on ecological niches, but also for practical purposes such as in conservation planning and wildlife management, including for cetaceans [155,156]. The models have been increasingly used in MSP [157], especially in designing MPAs [158] and for identifying areas of potential conflict between marine species and human activities [159–161] to inform mitigation measures [151,162,163]. They are also used for predicting how habitats might shift with changing oceanography dynamics [164] in unprecedented studied areas.

Simple mapping technique

In addition to the complex modelling techniques, it is also very important to apply a simple mapping technique to visualise and interpret the spatial distribution or occurrence patterns of a species. Descriptive models of spatial patterns [165], for instance, only depict the spatial pattern of the species abundance, or the relationship between the species distribution and the environment (in a descriptive manner), as well as the abundance distribution of species related to their habitat characteristics. In such simple spatial point-pattern analysis, only the species occurrence in spatial point-patterns is depicted, and no mathematical relations are built. An example of such a descriptive model is the visualization of the spatial distribution of a cetacean species created using GIS software such as ArcGIS 10.6.1 (Environmental Systems Research Institute, Inc.) based on sighting locations and number of individuals. The cetacean occurrence then can be related to the zoning system of a conservation area, habitat types, or depth preferences to assess area use by the cetacean species.

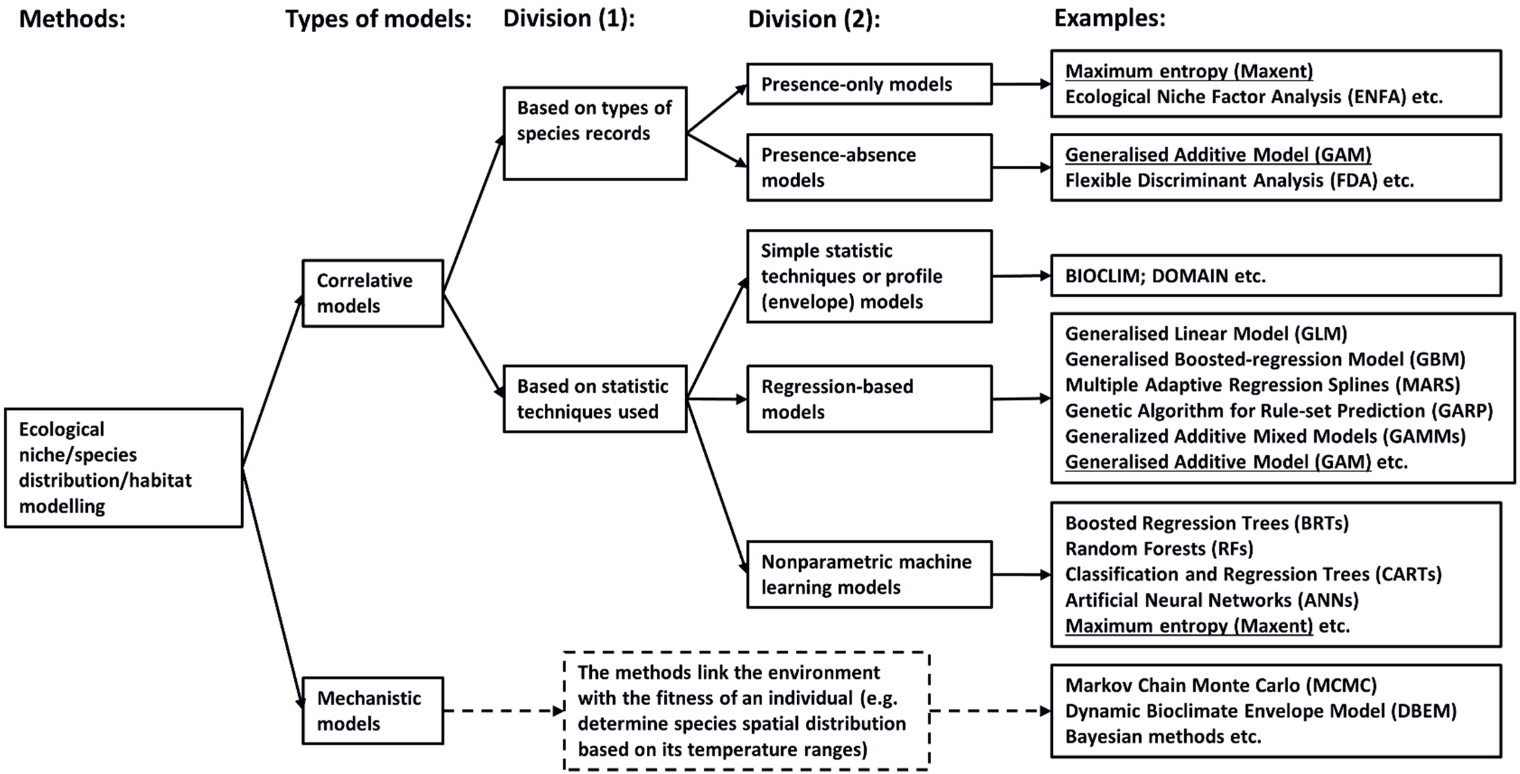

Fig. 1.4. Overview of available methods for ecological niche/species distribution/habitat modelling. Based on data availability (presence-only data, and pseudo-absences) and research objectives, only Maxent and Generalised Additive Model (GAM) were used in this thesis.

Box 1.3. The classification of ecological niche/species distribution/habitat methods

The habitat models can be divided into 'correlative models' and 'mechanistic models' [149,153]. The correlative model correlates the presences and/or absences of a species to environmental variables [153]. Within the correlative models, two categories are recognised: 'presence-only models' (e.g., Maximum entropy, Maxent [166], Ecological Niche Factor Analysis, ENFA [167]) and 'presence-absence models' (e.g., Generalised Additive Model, GAM [168], Flexible Discriminant Analysis, FDA [169]). In principle, any model available to date can be used depending on the type of species sightings recorded i.e., presence-only or presence-absence data. In fact, the only reliable information on species occurrence is their recorded presence, and unlike presence data, reliable absence data are rare and hard to obtain [170]. Therefore, 'presence-absence models' with true absence data are hardly employed. Alternatively, 'presence-absence models' substitute the true absences with pseudo-absences which could be in the form of background data by establishing the environmental domain of the study or by simply generating non-presence data [171]. The less used mechanistic models link the environment with the fitness of an individual e.g., determine species spatial distribution based on its temperature range.

Another model classification also exists based on statistic techniques used: simple statistic techniques from 'profile (envelope) models' (e.g., BIOCLIM [172]; DOMAIN [173]), 'regression-based models' (e.g., Generalised Linear Models, GLMs [174]; GAM [168]), and non-parametric 'machine learning models' (e.g., Maxent). Simple 'profile/envelope models' such as BIOCLIM and DOMAIN using only presence data and they have the poorest performance [175,176]. Widely used 'regression-based models' such as GLMs and GAMs outperform the simpler models [177], and GAMs are better in dealing with modelling complex ecological systems and are able to model non-linear function by using smoothers [178]. Other regression models are Generalised Boosted-regression Models (GBMs), Multiple Adaptive Regression Splines (MARS) and Genetic Algorithm for Rule-set Prediction (GARP) [178,179]. Recently, several studies using satellite telemetry data have used Generalised Additive Mixed Models (GAMMs) [94,180–182] that are possible to include random effects, because the tagged animal's serial positions are not independent [183]. Lastly, 'machine learning models' such as Boosted Regression Trees (BRTs), Random Forests (RFs), and especially Maxent become popular over the last decade, while a few methods like Classification and Regression Trees (CARTs) and Artificial Neural Networks (ANNs) have been around for some time [146,178]. Maxent is the most commonly used method in habitat modelling and has been found to perform well in comparison to other established modelling techniques [178,184]. Recent emphasis on machine-learning methods indicate that new methods will continue to be developed and are constantly appearing.

1.4.3. Data availability

Reliable data are essential for the development of a spatial population distribution as the basis for successful conservation planning. The available animal occurrence data, however, are rarely readily available for most species [185] as is the case for cetacean records in many regions in Indonesian waters. Surveying such vast areas is expensive and logistically demanding [13,126,186,187]. The complex environments such as remote offshore locations, the poor weather and sea conditions that tend to limit the survey accessibility are also other principal constraints. Cetacean species are difficult to record, due to the nature of their highly mobile and elusive traits [188–191]. Existing information on cetacean presence in Indonesia is primarily based on whaling operations [78,192], strandings [193,194], and incidental sightings

[77]. Cetacean monitoring programs have only been recently conducted at several sites in the country, mainly collected during coastal boat surveys, particularly with platforms of opportunity, as well as limited-coverage aerial surveys [37,55,195,196]. Because most of the data come from visual observations, this information is inherently limited in space and time. Only more recently a satellite tagging study has been conducted to complement the conventional data collection methods [76]. In the following, I elaborate three dataset types used in this study that currently represent the best source of information on cetacean occurrence in Indonesia: historical whaling data, contemporary non-systematic data, and telemetry data.

Historical whaling data/museum data/archived data

The information from the past such as historical whaling data, museum data, or archived data is a good alternative to pay off the current relatively poor-data availability [187,197,198]. Some large cetaceans were hunted massively across all oceans for two centuries during Yankee whaling era [31]. The long history of the species exploitation provides information of their past coarse distribution as well as their current consequences. For instance, the depletion of male sperm whales in a population due to historical exploitation has resulted in a lack of information on possible recovery of the species since the time of the exploitation [31,199]. Integrating data from the past into current macroecological analyses will enhance our understanding of the underlying reasons for contemporary patterns [200]. In addition, historical records are an important source of information on the abundance of exploited marine species, especially those that were earliest exploited before the commencing of modern scientific research [201]. The use of historical data also reflects the opportunities to improve the usability of available data [14].

Some common issues, however, exist when employing historical data for contemporary study, mainly difficulties in the interpretation [202] and the accuracy [203,204], since they are made in the era with limited cartographic technology. However, current analytical tools, allow us to use such data to improve the interpretation, for instance by applying habitat modelling to clarify the better distribution of the species. Historical whaling data have been successfully used in habitat modelling studies [197,205,206].

Non-systematic data (platforms of opportunity, incidental sightings)

Conducting an elaborate systematic survey such as line transect distance sampling [155,207] usually involves devoted boats and observers and thus can be very costly [13,208], especially for developing countries. The cost of the standard dedicated surveys, however, may be reduced by using alternative survey methodologies. An alternative in the case of limited resources is using a low-cost method such as platforms of opportunity [209,210] by placing observers on vessels that conduct other activities. Confusingly, the term ‘platforms of opportunity’ is often used to describe opportunistic data, rather than platforms. The true opportunistic data include data from sighting logs [211], whaling [78,212], or strandings [193,194]. The main characteristic of such data is not effort-based (i.e., measurements of effort are often missing). An effort-related study conducted from a ‘platform of opportunity’ is better defined as one in which the platform is opportunistic, but the research is systematic. Incidental sightings reported by fishermen and volunteers are another useful data source.

In contrast to systematic survey data, opportunistic data are a common example of presence-only data, often represent the largest set of available data [205]. Cetacean sighting data in Indonesia mostly are collected opportunistically in areas of known occurrence or areas that are easy to survey. When collected over a long-term, opportunistic sighting data are a valuable source of information on temporal and spatial changes in cetacean occurrence [213,214]. Some common issues with using platforms of opportunity data, however, exist: (i) the variable temporal and spatial coverage of the study area that may influence the risk of sampling bias, and (ii) different data sources with different survey methods [178,215]. Combining such datasets to enhance the number of records, are the best option to allow spatial assessments to be generated [216]. This approach is necessary when the monitoring effort is low. Long term and pooled data are capturing both inter-seasonal and inter-annual variability in cetacean distribution [217]. Although the use of non-systematic data might provide limited data representation compared to systematically collected data, considering the scarce knowledge in Indonesia, this approach can be a very efficient and cost-effective method to accelerate the knowledge on cetacean occurrence to inform decision-makers.

Telemetry data

Obtaining detailed information on marine migratory animals such as cetaceans is difficult, since they are highly mobile and spend relatively little time at the surface [188,189]. Direct observations from ships or airplanes are limited to locations of traverse [27], hence only provides a snapshot and is unable to discover long migratory pathways and ecological aspects determining their movement [24,182]. Recent advances in satellite telemetry enabled the ability to remotely observe long-distance movements of animals in relation to ocean processes across large geographical and ecological scales [15,26,112,123]. Telemetry makes the observation more practicable and offers opportunities to analyse the spatial and temporal trajectories of animal movements [188]. This has led to evidence-based conservation measures for many marine megafauna [218]. Telemetry revealed key areas for policy makers to mitigate anthropogenic risks and to designate the location, size, and timing of MPA. It also can help assess their efficacy, and provide insights into the potential impact of climate change on pelagic species [15,107,219].

Telemetry data, however, are costly to collect and therefore the number of tagged animals can be too low to adequately represent population patterns [220,221]. Therefore telemetry data are hardly available for management applications [218]. Moreover, telemetry mostly records only specific life history stages of a focal species [98,222]. Although the knowledge of species movements increases with the sample size of tracked animals, relatively small sample sizes can already provide pivotal information for conservation actions [25,124,182,223]. Although telemetry data typically concern a limited number of samples over short time frames [224,225], they provide more dedicated and comprehensive benefits than opportunistic or non-systematic data. For instance, telemetry data can provide a more robust measurement of animal's habitat use (i.e., home range and core-use area) compare to observational data [226,227]. Knowledge on movement ecology such as the distribution, movements, and habitat use of cetaceans has been rapidly increasing with the expansion of satellite telemetry studies [228].

1.5. Knowledge gaps

In this introduction, the following knowledge gaps were identified:

1. Gaps between the official legal framework for cetacean governance, institutional arrangements, and actual implementation and enforcement of these policies exist, hampering cetacean conservation in Indonesia. The main shortcomings of the current legal framework need to be identified in order to suggest priorities to improve effective cetacean conservation.
2. The lack of information on the ecology of and important areas for cetaceans impedes the current conservation management. Cetacean studies are limited, especially in tropical areas with oceanic small islands, reef and topographic complexity like Indonesia. These studies include information on cetacean distribution, habitat preferences, and the environmental characteristics that determine their distribution and habitats. Current information is mainly available in the form of fragmented reports of species occurrence, and for spatial analysis of areas important for cetaceans in relation to current conservation areas, modelling of continuous surface distribution of cetacean species is needed.
3. The cetacean seasonal movement patterns, migratory corridors, home range, and habitat use are poorly understood in Indonesia. Migratory animals such as the cetaceans tend to be ignored when planning MPAs or in MSP, because obtaining large-scale migration data is difficult and expensive and may far exceed the spatial scale of planning. Determining migration lanes of marine biota for Indonesian MSP is difficult and no such method exists. Therefore, there is no rational basis to decide what migration routes to include as a zone or lane in MSP maps or to assess

whether area-based management tools (e.g., MSP, MPAs) are sufficient to conserve migrating cetaceans.

4. No spatial assessment of anthropogenic threats on cetaceans in Indonesia is available. It is not yet known what potential threats need to be managed to provide safe conservation areas and migration paths in the MPA and MSP development. A sound management plan that integrates the most effective measures to protect cetaceans from adverse anthropogenic impacts is clearly constrained by lack of knowledge about the species' critical habitats and their overlap with threats.
5. Limited systematic survey-based detailed information is available about cetacean species diversity, abundance and occurrence patterns in parts of Indonesia. The use of non-systematic and cost-effective survey techniques to support cetacean conservation planning by providing insights into spatio-temporal occurrence patterns and abundance estimation of cetaceans should be examined in marine park areas with knowledge-poor situations.

1.6. Aim, research questions, and outline of the thesis

This thesis aims to develop an approach to provide information to improve cetacean conservation management in Indonesia through suggestions for strengthening the governance and introduction of habitat-use-based spatial planning. For this purpose, the use of multiple complementary datasets and methods are demonstrated to reveal cetacean spatial distribution, habitat preferences, spatio-temporal occurrences and relative abundance to -ultimately- advise protection governance. To achieve this, the current thesis will address the following research questions:

RQ1. What are the gaps and main shortcomings of the current legal framework in Indonesia for effective cetacean conservation, and what are priority aspects to improve?

RQ2. What is the cetaceans' spatial distribution in Indonesia and which environmental characteristics determine this?

RQ3. What are potential migratory corridors and habitats of selected cetacean species and how do these relate to marine conservation systems and anthropogenic threats?

RQ4. How can cost-effective survey techniques support cetacean conservation planning by providing insights into spatio-temporal distribution and abundance of cetaceans in information-poor situations?

This thesis comprises of five research chapters (Chapters 2-6) with an introduction (Chapter 1) and a discussion synthesizing the acquired insights (Chapter 7). The links between the chapters are shown in Fig. 1.5. Each chapter will contribute the following to answer the research questions:

Chapter 1 (this chapter) introduces the context and research background that led to this study. It starts with the ecology of and threats for cetaceans and the situation of cetacean conservation in Indonesia. This is followed by elaborating on the area-based management approach, reviews the different habitat modelling approaches and different types of datasets available. Next, the knowledge gaps are summarised. Then, the chapter ends with the aim, research questions, and outline of the thesis. **Chapter 2** elucidates marine mammal protection governance in Indonesia, reviews the legal framework, institutional arrangement, and policy in three different layers (international, national, province), and identifies gaps and shortcomings in current regulations and key aspects to improve them.

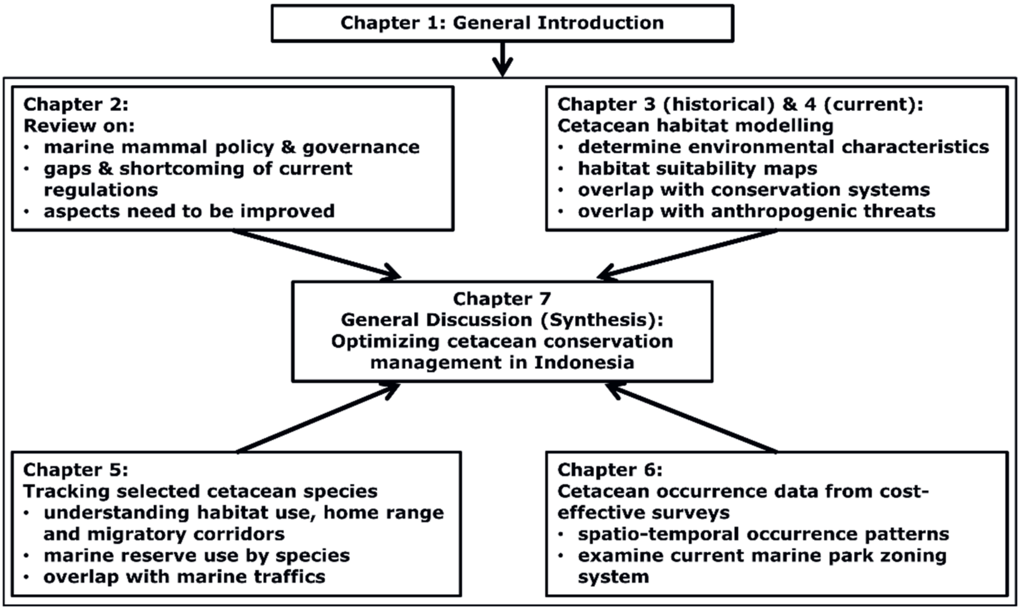

Fig. 1.5. Overview of the chapters of this PhD thesis.

Chapters 3-5 focus on the spatial distribution, habitat use and habitat preference of cetaceans. In each of the chapters, I apply several habitat modelling approaches and explore how different datasets (historical whaling data [1761-1920], current data [2000-2018], and telemetry data [2009 and 2011]) can complement each other and thereby strengthen the outcome of the research. **Chapter 3** unveils former seasonal distribution and habitat preferences of sperm whale using historical whaling data for whole Indonesian waters. Two habitat modelling are used, Maxent and Generalised Additive Model (GAM), Information on critical habitats and seasonal variability from this study can be used to direct future monitoring program and provided input for MPA and MSP establishment. **Chapter 4** presents current cetacean habitat suitability modelling for 15 selected species in 7 ecoregions or seascapes in

Indonesia using pooled multi-source data, and assesses overlap with MPA, MSP, and two anthropogenic threats: oil-gas concession areas and marine traffic. The results can support cetacean conservation management planning by providing priority areas, and be used a basis for anthropogenic threat mitigation. **Chapter 5** performs telemetry-based home range and habitat modelling to understand an important part of pygmy blue whale's (PBW) life cycle (i.e., migration), predict migratory corridors and core-use areas, and assesses overlap with marine reserves and marine traffic. The results can aid the adjustment of designated migration corridors and current MPA boundaries. Multi-national collaborations are encouraged for protecting cetacean key areas in the high seas.

Chapter 6 assesses cetacean diversity, spatio-temporal occurrence patterns, sighting frequency, and habitat preferences using non-systematic low-cost data (from platforms of opportunity and incidental sightings) for marine park management in Wakatobi National Park (WNP), Indonesia. This study demonstrates the use of platforms of opportunity as a cost-effective tool to provide valuable data on spatio-temporal occurrence and estimate relative abundance of cetaceans in areas with limited survey resources. **Chapter 7** draws together the major findings of individual chapters, discusses the potentials of using habitat-use-based spatial planning approach to solve cetacean governance and management challenges in Indonesia. Furthermore, this chapter discusses the implications and relevance of using multi-method approaches and different datasets to gain knowledge on policy and governance, and cetacean conservation hotspots to optimise the country's cetacean conservation management. Finally, the chapter presents recommendations for further research.

"We need to sharpen the science – our ability to collect and analyse the data – so that policy-makers can make good decisions."

Erich Hoyt

Chapter 2

A critical review of marine mammal governance and protection in Indonesia

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Published as: A. Sahri, P.L.K. Mustika, H.Y. Dewanto, A.J. Murk. (2020). A critical review of marine mammal governance and protection in Indonesia. Marine Policy, 117C: 103893. https://doi.org/10.1016/j.marpol.2020.103893

Abstract

The governance of marine conservation in Indonesia has been the subject of critique for decades. This paper elucidates and analyses the legal framework for marine mammal protection and current institutional arrangements, and reveals gaps and overlaps in the national legal and policy frameworks for marine mammal governance in the Archipelago. We reviewed available policies to assess the current regulation practices in the country's marine mammal protection. In total, five relevant international conventions, 28 Indonesian national regulations, and 16 provincial regulations on marine spatial planning were found. Progress on legal framework regarding marine mammal governance reveals three different phases: 1970s (species-centred approach), 1990s (site-based approach), and current (wider marine management approach). We summarised seven policies based on the following characteristics: species, site and other values. We identified functional overlap and unclear mandates as the main shortcomings of these regulations. Although marine mammal protection in Indonesia enjoys a set of regulations, the practical actions required by these regulations are still unclear. Protection gaps still exist, rendering conservation efforts less effective. The paper argues how an adequate and appropriate legal framework and institutional arrangements will ameliorate and strengthen marine mammal governance in Indonesia. We suggest some urgent-yet-lacking policies that should be added to the current regulations, including regulations on traditional whale hunting, the code of conduct for marine mammal watching tourism, standards for aquaria, and the legal basis for marine mammal stranding network and underwater noise pollution. We endorse the cetacean National Plan of Action for it is designed to enhance ecological and human-dimension research on cetaceans and address the detrimental effects of anthropogenic activities to the cetaceans. We suggest establishing a mechanism for cross-institutional coordination for more effective marine mammal protection in Indonesia. Becoming a full member of the Convention on the Conservation of Migratory Species of Wild Animals and International Whaling Commission will further strengthen the conservation management of marine mammals in Indonesia.

Keywords: institutional arrangement, legal framework, marine governance, marine mammal, marine spatial planning, policy

2.1. Introduction

Cetaceans are important top predators of the marine food chain and play a critical role in maintaining biodiverse and resilient ecosystems. However, several species of cetaceans are threatened. Based on International Union for Conservation of Nature (IUCN) online database [229], the status of more than a fifth of cetacean species that occur in Indonesian waters are listed as threatened species (Supplementary Table S1). Further, more than three quarter of other cetacean species are listed as 'Least Concern' or 'Data Deficient' making it difficult to assess its population status. There is a long history of anthropogenic pressures on marine mammals through historical and commercial whaling, habitat degradation, and other anthropogenic activities in the marine environment [36]. The anthropogenic threats include interactions with fisheries (entanglement, bycatch, prey depletion) [38], physical and acoustic disturbance (ship strikes, underwater noise from seismic activities and naval sonar) [43,44], and pollution [49], including oil spill, plastic debris, persistent organic pollutants and heavy metals, and other chemicals.

The Indonesian government has set up measures dedicated to improve the conservation of migratory species, including stipulation of several regulations intended to directly protect cetacean species as well as establishment of Marine Protected Areas (MPAs) that indirectly provide benefits to cetacean protection. Via MPAs many other marine species are also protected in their habitat, thus supporting total biodiversity [4,8]. Many policies have been designed and initiatives have been developed by the government in order to maintain and conserve marine resources. In 2006, during the Conference of the Parties to the Convention on Biological Diversity (COP-CBD) in Brazil, the Indonesian government declared its commitment to establish and manage MPAs covering an area of 10 million hectares by 2010. This commitment was strongly asserted again during the World Ocean Conference 2009 in Indonesia and the target size was readjusted to 20 million hectares by 2020 [114]. In addition to this effort, the Indonesian government also decided to formulate extra regulations. To name a few, the Indonesian government has declared all cetacean species as protected biota. This includes a ban on hunting and killing of marine mammals, prohibition of trade of these species or their derivate products with some exceptions. According to the Indonesian regulation, migration paths of marine biota, including cetaceans, now have to be incorporated into Marine Spatial Planning (MSP) [230]. Recently, the 2016–2020 National Action Plan for Cetacean Conservation has also been issued as guidance for cetacean conservation in Indonesia [53,231].

Although officially all cetacean species are protected by international or Indonesian national regulations, in reality they are not. The limited governance quality of some marine conservation initiatives has polarised opinions for decades, resulting in intense debates and serious critique [120], particularly regarding their ability to provide real protection to specifically targeted animals. In addition, the implementation in local policies, and enforcement and effectiveness of the chosen policy measures, remains debated and has been subject of inquiry by many [122]. In addition, the lack of proper implementation in institutional arrangements has contributed to the current problems with marine management effectiveness, see e.g., Ref. [232]. A better understanding of the strengths, weaknesses, gaps and overlaps within the legal framework can help in overcoming the often complex issues arising from the enactment of regulations.

The aim of this study was to elucidate and analyse problems with the legal framework for marine mammal protection and reveal gaps and overlaps in the national legal and policy framework for cetacean governance in Indonesia. This study was conducted to provide a structured overview of the legal framework, institutional arrangement, and policies related to marine mammal governance and protection in Indonesia. The following three questions will be answered: (i) what are the existing marine mammal protection policies and regulations in Indonesia? (ii) what are the gaps and main shortcomings in the current marine mammal protection regulations? (iii) what are the most important aspects to improve marine mammal governance and protection in Indonesia?

2.2. Materials and methods

2.2.1. Data collection

To obtain data on Indonesian regulations regarding cetacean governance and protection, policy documents issued by the central national government, relevant ministries and provincial government (on marine spatial planning) within the period of 1970–2018 were reviewed. Most of the policy documents issued in Indonesia are now available online, although mostly only in Bahasa Indonesia. Online platforms such as peraturan.go.id (an online platform to disseminate all the laws and regulations managed by the Directorate General of Legislation of Indonesian Ministry of Law and Human Rights) and jdih.kkp.go.id (a legal documentation and information network of Indonesian Ministry of Marine Affairs and Fisheries) were used.

Since the terms 'governance' and 'protection' are not clearly defined in many regulation documents, specific terms were applied in combination to comprehend the main message of the policy documents. The specific combination of terms such as 'cetacean protection from trading and hunting', 'cetacean habitat protection' and 'protection of cetacean migration corridor' as well as 'marine conservation' and 'marine biota management' in general were used to determine whether a particular policy can be categorised as a regulation relating to cetacean protection or not.

2.2.2. Data analysis

To answer the first research question (Fig. 2.1), an extensive literature review was performed of legal and policy documents issued by the central government and relevant ministries. These include International conventions that were adopted/ratified by the Indonesian government. Provincial regulations on marine spatial planning were also included. The review summarised the core aspects (content analysis) of each regulation and analysed whether it provides incentives to protect cetaceans, and in what form. Subsequently, the findings were compiled and presented in a tabular form allowing for comprehensive interpretation.

The second research question was answered through three steps. First, we mapped the inter-relation among the existing regulations (policy mapping) and subsequently performed adherence analysis [233]. The policies extracted from existing regulations were grouped based on regulation content category. For instance, regulations that directly mention cetacean species as protected biota were grouped together. Second, problems with institutional arrangements such as potential issues related to functional overlap and unclear mandates of regulations in marine mammal governance were identified. Third, the policies (the specific measure regarding marine mammal management) were summarised and reviewed to obtain a comprehensive understanding.

To be able to answer the third question, striking points and findings from the previous parts were discussed. Further challenges and possible options to improve cetacean protection policy were also discussed. The detailed data analysis methodology of this study is presented in Fig. 2.1.

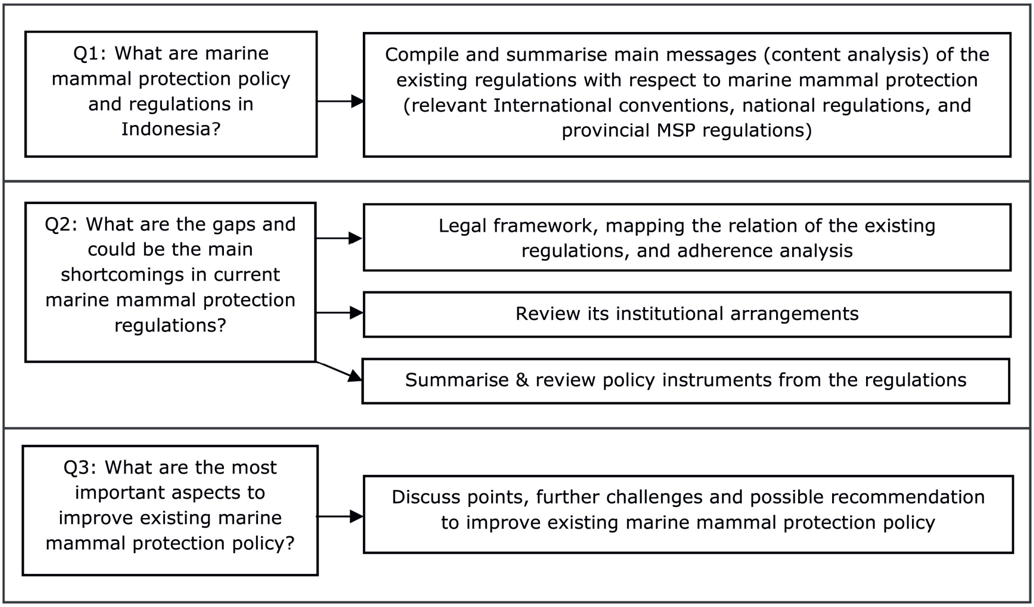

Fig. 2.1. Schematic overview of the analyses performed in this study.

2.3. Results

In total, five relevant international conventions (Table 2.1) and 28 Indonesian national regulations (Table 2.2) related to marine mammal protection policy, as well as 16 provincial regulations on marine spatial planning were found (Table 2.3). The presentation of the main gaps and shortcomings of the current regulations is divided into three subsections: legal framework, institutional arrangements and policies.

Table 2.1. International conventions that are relevant for marine mammal governance in Indonesia.

No.	Name of Conventions	Main messages with respect to marine mammals	Remarks
1.	International Convention for the Regulation of Whaling (ICRW) 1946	The ICRW is the legal basis for the International Whaling Commission (IWC). ICRW aims to protect all whale species from overhunting and to ensure proper conservation and development of the global whale stocks. Almost all whale species are protected from commercial killing, although it is still debated whether or not to include small cetaceans. ICRW regulates any activity that may threaten the whale stocks. IWC asked its members to adopt regulation specifically dedicated for conservation and utilization of whale resources, including the development of sanctuary areas where whaling activities are strictly prohibited. IWC manages whaling activities, including a moratorium on commercial whaling, catch limits for aboriginal subsistence whaling, management of scientific whaling, and it handles objections to IWC whaling bans.	Indonesia is currently not a member of IWC. However, IWC's competences have been expanded beyond whaling (see Ref. [234]), therefore it is worthwhile for Indonesia to further explore the benefits from joining the IWC.
2.	Convention on International Trade in Endangered Species of Wild Flora and Fauna (CITES) 1973	All threatened species (including their recognizable parts or derivatives) which are trafficked all over the world are subject to strict regulation and only allowed in highly exceptional conditions. CITES issued appendices I, II, and III lists. Appendix I: the most endangered species that are threatened with extinction and prohibited for trading, except for non-commercial purposes (e.g., scientific research). Appendix II: species that are not necessarily now threatened with extinction but that may become so, unless trade is strictly controlled. Appendix III: species that are not necessarily threatened with extinction globally and are listed after one member state has asked other parties for assistance in controlling trade in a species. All marine mammals which occur in Indonesian waters are listed in Appendices I (12 species) and II (23 species) of the convention.	Indonesia joined CITES as an accession member and ratified the convention through Presidential Decree No. 43/1978 in December 1978.
3.	Convention on the Conservation of Migratory Species of Wild Animals, CMS (Bonn	The CMS provides the legal foundation for internationally coordinated conservation measures throughout a migratory range. CMS parties should immediately protect the migratory species of its Appendix I (endangered migratory species), and encourage states (particularly range states) to conclude an agreement for conservation and	Indonesia is non-party of CMS. Indonesia is an MoU Signatory for marine turtles (by May 2005). However,

No.	Name of Conventions	Main messages with respect to marine mammals	Remarks
	Convention) 1979	management of migratory species in Appendix II (migratory species to be the subject of agreement). CMS requires the parties that are range states to have scientific knowledge on identification of migratory species, description on the range, and migration route of the species; to conserve and restore their habitat as well as control adverse factors for the species. Most of the marine mammals that occur in Indonesian waters are listed in its Appendices I (6 species) and II (18 species). CMS prohibits taking, hunting, fishing, capturing, harassing, or deliberate killing of these migratory species. By 2011, seven resolutions focusing on cetacean conservation have been issued by CMS, including future actions for several whales and reduction of adverse human-induced impacts (e.g., ocean noise) on cetaceans.	Indonesia is not an MoU Signatory for dugong and cetaceans, although Indonesia is a range state of these migratory species.
4.	United Nations Convention on the Law of the Sea (UNCLOS) 1982	Part V (Economic Exclusive Zones, EEZ) of UNCLOS specifically mentions highly migratory species (Article 64), and marine mammals (Article 65). On Part VII (High Seas) Section 2, UNCLOS explicitly stresses the importance of and encourages international cooperation for living resources of the high seas for all ratifying countries. Article 120 specifically mentions marine mammals as a conservation target.	Ratified by Indonesia in 1985 through Law No. 17/1985. Indonesia is a party to this convention.
5.	Convention on Biological Diversity (CBD) of the United Nations 1992	The CBD recognises the traditional dependence of humans on biological resources and encourages the parties to manage the traditional use of biological resources sustainably. CBD calls on parties to establish a system of protected areas to conserve biological diversity, to actively participate in any aspect of conservation effort and to control risks associated with the use of biological diversity. CBD suggests incorporating consideration of biodiversity conservation within national policy-making and encourages cooperation among parties in all activities regarding biological resources. CBD was later followed by the enactment of the Jakarta Mandate in 1995 that directed all member states to develop an action plan for implementing CBD for marine and coastal biodiversity and to ensure that coastal and marine living resources will be used sustainably. The mandate includes establishment of an integrated marine-coastal area management and marine protected areas.	Ratified by Indonesia through Law No.5/1994. Indonesia is a party to this convention.

Table 2.2. National regulations for marine mammal protection and governance in Indonesia (*Indonesian words in Italics*).

No.	Name of Regulations	Main messages with respect to marine mammals
1.	Minister of Agriculture (MoA) Decree No.327/1972 on Protection of wild animals	The Dugong is listed as a protected wild animal in the regulation.

No.	Name of Regulations	Main messages with respect to marine mammals
2.	MoA Decree No.35/1975 on Protection of wild animals	The protected wild animals listed in the regulation include freshwater- and marine dolphins.
3.	MoA Decree No.327/1978 on Protection of wild animals	Addendum of Blue, Fin, and Humpback whales to the protected wild animal list.
4.	Presidential Decree No.43/1978 on Ratification of Convention on International Trade in Endangered Species of Wild Flora and Fauna (CITES)	All marine mammals which occur in Indonesian waters are listed in Appendix I (12 species) and Appendix II (23 species) of the convention.
5.	MoA Decree No.716/1980 on Protection of wild animals	Addition of all whales to the protected wild animal list.
6.	Law No.17/1985 on Ratification of the United Nations Convention on the Law of the Sea (UNCLOS)	Explicitly stresses the importance of and encourages international cooperation for marine mammal conservation for all ratifying countries. As a highly migratory species, marine mammals are a conservation target.
7.	Law No.5/1990 on Conservation of living natural resources and their ecosystems	Regulates all aspects related to conservation, both space and natural resources, and aims to regulate the protection of life buffer systems, preservation of the diversity of plant and animal species and their ecosystems, and the sustainable use of biological natural resources and their ecosystems. The law also mentions types of nature reserves. This law divides animals into protected and unprotected species.
8.	Presidential Decree No.32/1990 on Management of protected areas	Indicates the necessity to establish protected areas and guidelines for management of protected areas. The regulation also describes types of nature reserves and the criteria for establishment of each type. It specifically mentions marine nature reserves.
9.	Law No.5/1994 on Ratification on the United Nations Convention on Biological Diversity (CBD)	CBD suggests establishing a system of protected areas, controlling risks associated with the use of biological diversity, incorporating consideration of biodiversity conservation within national policy-making, collaborating among contracting states in all activities regarding biological resources, and developing action plans for implementing CBD in terms of marine and coastal biodiversity through integrated coastal area management and marine protected areas. The CBD recognises the traditional whale hunting in Indonesia and as a CBD member, Indonesia is expected to manage the whale hunting sustainably.
10.	Government Regulation No.68/1998 on Nature reserves and nature protected areas	Describes in-situ conservation, establishment criteria, utilization, and management plans. The in-situ conservation is categorised into nature reserves and nature protected areas. The nature reserves consist of nature preservation areas (*Kawasan Cagar Alam*) and wildlife sanctuaries (*Kawasan Suaka Margasatwa*). Nature protected areas consist of national park areas (*Kawasan Taman Nasional*), great forest park areas (*Kawasan Taman Hutan Raya*), and nature park areas (*Kawasan Taman Wisata Alam*). Derivative regulation of Law No.5/1990.
11.	Government Regulation No.7/1999 on Preservation of flora and fauna	Flora and fauna are divided into protected and unprotected species. Flora and fauna preservation could be done in-situ or ex-situ. All marine mammals in Indonesia

No.	Name of Regulations	Main messages with respect to marine mammals
		are protected from deliberate killing and trading. Derivative regulation of Law No.5/1990.
12.	Government Regulation No.8/1999 on Exploitation of wild flora and fauna	Strict regulation for protected and unprotected plants and wildlife from being captured, hunted, traded, exchanged or raised for pleasure. Derivative regulation of Law No.5/1990.
13.	Government Regulation No.19/1999 on Marine pollution and/or destruction control	Prohibits and regulates activities that will cause marine pollution and destruction. Mandates assigning sea water quality standards and marine ecosystem destruction standards.
14.	Law No. 31/2004 on Fisheries (Amended by Law No. 45/2009)[a]	Marine mammals are considered as 'fish' under this law (Article 1 clause 4). The law addresses fishery conservation (Article 1 clause 8). In order to support the fishery resources management policy, protected fish species and aquatic conservation areas need to be stipulated (Article 7 clause 1). Since marine mammals are considered as fish, the fishery conservation and stipulation of aquatic conservation areas benefit marine mammals as well.
15.	Law No. 27/2007 on Management of coastal area and small islands (Amended by Law No. 1/2014)[a]	Coastal and small island conservation is organised to protect migration corridors and habitats of fish and other marine biota (Article 28). This law also explains about zoning plans for marine, coastal and small island areas (Indonesian: *Rencana Zonasi Wilayah Pesisir dan Pulau-Pulau Kecil*, abbreviated as *RZWP3K*). Although it doesn't explicitly state the protection of marine mammals, it highlights the importance of migration corridors and habitat protection.
16.	Government Regulation No. 60/2007 on Conservation of fish resources	Conservation and sustainable use of fish resources, including their habitat. Marine mammals are considered as 'fish' under this regulation (Article 1 clause 6). Stipulation of aquatic conservation areas shall take into account ecological aspects: biodiversity, spawning area, nursery area, migration corridor, etc. Four forms of aquatic conservation areas are defined: aquatic national parks, aquatic tourism parks, aquatic nature reserves, and fishery sanctuaries. The utilization of fish resources includes use for research, aquaculture, trading, aquaria, exchange or raising for pleasure. The regulation divides fish into protected and unprotected fish. Derivative regulation of Law No. 31/2004 (amended by Law No. 45/2009). Protected fish refer to CITES Appendices species; hence all marine mammals which occur in Indonesia belong to protected species.
17.	MMAF Regulation No. 16/2008 on Management planning of coastal area and small islands (amended by MMAF Regulation No. 34/2014)[a]	Marine biota migration paths are considered to be sea lanes (Article 15 clause 6) that must be included in the establishment of a zoning plan for coastal and small island areas (*RZWP3K*).
18.	Ministry of Marine Affairs and Fisheries (MMAF) Regulation No. 17/2008 on Conservation area in the coastal area and small islands	Four forms of coastal and small islands conservation areas are defined: coastal sanctuaries, small islands sanctuaries, coastal parks, and small island parks. Core zones must be determined in each type of conservation area. The core zone is part of the conservation area which serves, among

No.	Name of Regulations	Main messages with respect to marine mammals
		other things, as a spawning area, nursery area, and migratory corridor of marine biota (Article 32 clause 1). Derivative regulation of Law No. 27/2007 (amended by Law No. 1/2014). Although it doesn't explicitly state the protection of marine mammals, it provides the opportunity to protect them by stipulation of the conservation areas.
19.	MMAF Regulation No. 2/2009 on Procedures for stipulation of aquatic conservation areas	Stipulation of the four forms of aquatic conservation areas have to take into account ecological aspects including the existence of habitat, spawning area, nursery area, and migration corridor for certain types of fish that have values and conservation interests (Article 4 clause 2).
20.	Law No.32/2009 on Environmental protection and management	Environmentally sustainable development must be done through planning policies, rational exploitation, development, restoration, supervision, and control. In terms of marine mammal management, this law supports protection of natural habitats and regulation of pollution that can negatively impact the marine ecosystem.
21.	MMAF Regulation No. 30/2010 on Management and zoning plan of aquatic conservation areas	Protection of migration corridors of marine biota is included in the stipulation of sustainable fishing zones of the aquatic conservation areas (Article 19 and 26).
22.	Government Regulation No.62/2010 on Utilization of small outlying islands	Utilization of small outlying islands for environmental sustainability can be implemented by assigning outlying islands as conservation areas (Article 8 and 9). Derivative regulation of Law No. 27/2007 (amended by Law No. 1/2014).
23.	MMAF Regulation No. 12/2012 on Open seas fisheries	Any vessel fishing on the open seas that catches marine mammals unintentionally while catching tuna or other pelagic species has to make sure the animals are released alive (Article 39) and the bycatch species must be reported to the port authority (Article 42).
24.	MMAF Regulation No. 30/2012 on Capture fishery in fishing territory of Indonesia (amended twice by MMAF Regulation No. 26/2013 and MMAF Regulation No. 57/2014)[a]	Any fishing vessel which obtained a fishing permit (Indonesian: SIPI) has to apply conservation measures to protect certain species ecologically related to tuna from bycatch, including marine mammals (Article 73 clause 1 and 2). The bycatch species must be released alive and must be reported to the port authority (Article 73 clause 4).
25.	Law No. 32/2014 on Marine Affairs	The government must undertake effort to protect the marine environment through marine environment conservation, including for migratory species, particularly marine mammals (Article 50 and its Explanation). Marine conservation could also be applicable to high seas (Article 11). International cooperation on marine resources conservation and management is stimulated (Chapter VII).
26.	MMAF Decree No.6/2014 on Management planning and zoning of Savu Sea Aquatic National Park and adjacent waters 2014–2034	Corridors for marine protected animals have been set up in Savu Sea National Park. Cetacean population management developed through regulating fishing gears, considering migration seasons, bycatch management, regulating shipping routes, and mining activities including seismic within the park.
27.	MMAF Decree No.79/2018 on National action plans for marine mammals conservation 2018–2022	The stipulation of national action plans for conservation of dugongs and cetaceans (includes all whales and marine dolphins) for the period of 2018–2022.

No.	Name of Regulations	Main messages with respect to marine mammals
28.	Presidential Decree No. 83/2018 on Tackling marine waste	The stipulation of national action plans for accelerating marine waste reduction management. This document describes the detailed strategy, program, activities, and institutions that are responsible to reduce marine waste including plastics for period of 2018–2025.

[a] The parts of these regulations that are relevant to marine mammal governance remain the same after the amendment.

Table 2.3. The provincial regulations on marine spatial planning (*Rencana Zonasi Wilayah Pesisir dan Pulau-Pulau Kecil*, or *RZWP3K*) in Indonesia that take into account marine mammal governance.

No.	Name of Regulations	Main messages with respect to marine mammals
1.	Provincial Regulation of North Sulawesi No. 1/2017 on a zoning plan for the coastal areas and small islands for 2017–2037	In determining sea lanes, the migration corridors [a] of marine biota must be included (Article 12). The marine biota mentioned in this regulations, however, are only turtles and fish (Appendix II of the regulation). No marine mammal species mentioned.
2.	Provincial Regulation of West Sulawesi No.6/2017 on a zoning plan for the coastal areas and small islands for 2017–2037	In determining sea lanes and conservation areas, the migration paths [b] of marine biota must be included (Article 13). Specifically mentions the migration paths of turtles (for landing and laying eggs), aquatic protected fish, and marine mammals (Appendix of the regulation). Vessels must lower their speed when passing the migration paths (Article 58 clause 1). Fishing activities are prohibited in the migration paths (Article 58 clause 2). Mandates research on the identification of marine mammals species and their migration patterns, and development of a surveillance and monitoring system for the migration paths.
3.	Provincial Regulation of West Nusa Tenggara No.12/2017 on a zoning plan for the coastal areas and small islands for 2017–2037	The migration paths of marine biota must be stipulated and protected (Article 47). The migration paths must be synchronised with other marine spatial uses. Specifically mentions the migration paths of turtles, sharks, whales, and dugongs (Article 48). Regulates the type of fishing gear that can be used in conservation areas, migration paths, spawning and nursery areas (Article 61). Mandates research on the identification of types of migratory species and their migration patterns, development of a surveillance and monitoring system for the migration paths, and deployment of special signs for the migration paths.
4.	Provincial Regulation of East Nusa Tenggara No.4/2017 on a zoning plan for the coastal areas and small islands for 2017–2037	This province has the largest migration corridors of cetaceans and these are stipulated as cetacean protected zones within the zoning plan (Article 21). The corridors, however, are integrated into the use zones that allow fishing activities by only applying cetacean-friendly fishing gear (Article 19, Explanation section). Mandates research on identification of the types of migration paths and patterns, and behaviour of marine mammals and other large biota, development of a migration path monitoring system, and synchronisation of the migration paths with other marine spatial uses.
5.	Provincial Regulation of Central Sulawesi No.10/2017 on a zoning plan for the coastal areas and	The migration paths of marine biota must be synchronised with other marine spatial uses (Article 31). The migration paths must be protected in determining conservation areas. Regulates a passing vessel on a migration corridor or conservation area to lower the vessel speed and commission a crew member to watch

No.	Name of Regulations	Main messages with respect to marine mammals
	small islands for 2017–2037	out for migratory biota (Article 59). Specifically mentions migration corridors of turtles, marine mammals (whales, dolphins, dugongs), and several fish species (marine eels, skipjack tuna) (Article 34). Prohibits fixed fishing gear in the migration paths (Article 45). Mandates research on identification of migratory species and their migration patterns, and behaviour of marine mammals and other large biota, development of a migration path monitoring system, and synchronisation of the migration paths with other marine spatial uses.
6.	Provincial Regulation of Lampung No.1/2018 on a zoning plan for the coastal areas and small islands for 2018–2038	In determining sea lanes, migration paths of marine biota must be considered (Article 10). The migration paths need to be protected or strictly regulated. Specifically mentions migration corridors of turtles and marine mammals (Article 28). Vessels must lower their speed when passing the migration paths (Article 53). Mandates research on identification of the lane types, migration patterns, and behaviour of marine mammals and other large biota, development of a migration path monitoring system, and synchronisation of the migration paths with other marine spatial uses.
7.	Provincial Regulation of East Java No.1/2018 on a zoning plan for the coastal areas and small islands for 2018–2038	In determining sea lanes and conservation areas, migration corridors and migration paths of marine biota must be considered. The migration paths together with spawning and nursery grounds must be protected within the conservation areas (Article 10 clause 3). The migration paths must be synchronised with other marine spatial uses (Article 12 clause 4). The marine biota mentions in this regulation, however, are only turtles and certain fish (pelagic and demersal fish) (Article 47 and 48). No marine mammal species mentioned. Restricts human activities that potentially affect the migratory species. Mandates research on identification of the lane types, migration patterns, and behaviour of marine biota, deployment of special signs for the migration paths, monitoring and evaluation of human activities around the migration paths.
8.	Provincial Regulation of West Sumatera No. 2/2018 on a zoning plan for the coastal areas and small islands for 2018–2038	This regulation does not state the migration paths of marine biota in sea-lanes designation. However, this regulation prohibits catching protected marine biota (Article 43, 46, and 60). Since the absence of migration paths within current regulation and zoning plan, research on identification of migration paths of turtles, marine mammals, and certain fish is needed as a basis for future migration path stipulation within future marine spatial planning (Appendix VII of the regulation).
9.	Provincial Regulation of South Kalimantan No. 13/2018 on a zoning plan for the coastal areas and small islands for 2018–2038	The migration paths must be synchronised with other marine spatial uses (Article 9). The migration paths include spawning and nursery grounds for endangered species. The marine biota mentioned in this regulation includes turtles, dugongs, whale sharks, freshwater- and marine dolphins (Article 28 and 41). The migration paths must be protected in establishment of a conservation area. Regulates human activities around the migration paths. Vessels passing a migration corridor must lower the vessel speed and commission a crew to watch out for migratory biota (Article 41 clause 10). Mandates research on identification of the lane types, migration patterns, and behaviour of turtles, dolphins, dugongs and other marine mammals, development of a migration path monitoring system, and synchronisation of the migration paths with other marine spatial uses.

No.	Name of Regulations	Main messages with respect to marine mammals
10.	Provincial Regulation of Maluku No. 1/2018 on a zoning plan for the coastal areas and small islands for 2018–2038	In determining conservation areas, migration paths, spawning and nursery ground must be considered and protected (Article 28). The migration paths are for protected marine biota (Article 14 clause 6). The migration paths must be synchronised with other marine spatial uses (Article 13 clause 1 and Article 37 clause 2). Specifically mentions the migration paths of cetaceans including dugongs and dolphins (Article 39). Prohibits fixed fishing gears in the migration paths and prohibits the captivity of megafauna including turtles, dugongs, dolphins, and whales (Article 39). Vessels must lower their speed when passing the migration paths (Article 60).
11.	Provincial Regulation of Kalimantan Utara No. 4/2018 on a zoning plan for the coastal areas and small islands for 2018–2038	The migration paths must be synchronised with other marine spatial uses (Article 26 clause 2). The migration paths are for protected marine biota (Article 46 clause 1). The marine biota mentioned in this regulation, however, are only turtles and pelagic fish (Article 26 clause 5). No marine mammal species mentioned. The migration paths must be stipulated both in use zones and conservation areas. Vessels must lower their speed when passing the migration paths (Article 46 clause 2). Mandates research on spatio-temporal monitoring of migratory biota, identification of migratory biota density, and mapping the migration paths of turtles and pelagic fish.
12.	Provincial Regulation of Maluku Utara No. 2/2018 on a zoning plan for the coastal areas and small islands for 2018–2038	In determining conservation areas, migration paths must be included and protected. Specifically mentions the migration paths of marine mammals (dolphins, whales), and turtles (Article 32). This regulation prohibits protected marine biota catching (Article 38 clause 2). Regulates a passing vessel on a migration corridor or conservation area to lower the vessel speed and commission a crew to observe migratory biota (Article 49 clause 1).
13.	Provincial Regulation of Yogyakarta No. 9/2018 on a zoning plan for the coastal areas and small islands for 2018–2038	This regulation does not mention the migration paths of marine biota in sea-lanes designation. However, this regulation requires surveillance and protection of protected biota (Article 7 clause 2). Since the absence of migration paths within this regulation and zoning plan, future research on identification of migration paths of migratory biota is needed (Appendix IV of the regulation).
14.	Provincial Regulation of Gorontalo No. 4/2018 on a zoning plan for the coastal areas and small islands for 2018–2038	In determining sea lanes and conservation areas, the migration paths of marine biota must be included. Prohibits the captivity of endangered species (Article 45 clause 3 and Article 46 clause 2) (refers to the CITES term, Article 7 and 8). Prohibits fixed fishing gear in the migration paths (Article 45 clause 3). The migration paths must be synchronised with other marine spatial uses (Article 31 clause 1). Specifically mentions the migration paths of turtles, marine mammals (dolphins, whales, dugongs), and certain fish (marine eels, skipjack tuna) (Article 31 clause 4 and Article 34). Vessels must lower their speed when passing the migration paths (Article 58 clause 8). Mandates research on identification of migratory species and their migration patterns, and behaviour of marine mammals and other large biota, and development of a migration path monitoring system.
15.	Provincial Regulation of Central Java No. 13/2018 on a zoning plan for the coastal areas and small	The protected species and their migration paths must be protected (Article 13 clause 2). The protected species mentioned in this regulation, however, are only marine eels and turtles (Article 34). No marine mammal species mentioned. Shipping traffic in the migration paths is allowed with lowered vessel speed or by

No.	Name of Regulations	Main messages with respect to marine mammals
	islands for 2018–2038	applying ship routing system (Appendix III of the regulation).
16.	Provincial Regulation of SE Sulawesi No. 9/2018 on a zoning plan for the coastal areas and small islands for 2018–2038	The protected species and their migration paths must be protected (Article 7 and 9). Specifically mentions the migration paths of whale sharks, dolphins, and turtles (Article 23 clause 4). In determining conservation areas, migration paths of marine biota must be included (Article 39 clause 3). Vessels must lower their speed when passing the migration paths (Article 45 clause 4). Mandates research on identification of the lane types, migration patterns, and behaviour of marine mammals, turtles, whale sharks, development of surveillance and monitoring system for the migration paths, and synchronisation of the migration paths with other marine spatial uses.

[a] Migration corridors: special areas or zones on a map intentionally designed for migration routes of marine biota.
[b] Migration paths: lines only indicating the presence of migration routes of marine biota.

2.3.1. Legal framework

Almost a half century preceding this study, from 1972 to 2018, the Indonesian government showed high commitment in marine biota protection and marine management in general. In the first decade starting from 1970s, the general basis for marine biota protection was drawn up, and indicated the main strategic lines of policy areas from a species-centred point of view. The regulations regarding marine mammal management were basically enacted regulations that mentioned several endangered and vulnerable species as protected biota and prohibited of their exploitation. The Indonesian government conforms to global initiatives by adopting several relevant international agreements into its national legal framework, as well as establishing its own legal framework that is needed for national purposes. Later on, the issues were changed in line with the more recent notion of site-based management, such as marine protected areas [12] and marine spatial planning [19,79]. Within the legal framework, we distinguish several international policies that are relevant for marine mammal management, the national legal framework for marine mammal management, and the adherence of Indonesia to international conventions.

2.3.1.1. Relevant international policies on marine mammal management

Five international conventions and agreements related to marine mammal governance were found (Table 2.1), of which three were ratified entirely by the Indonesian government, namely the Convention on International Trade in Endangered Species of Wild Flora and Fauna (CITES 1973), the United Nations Convention on the Law of the Sea (UNCLOS 1982), and the Convention on Biological Diversity of the United Nations (CBD 1992). These three conventions were ratified because of their benefits for and in line with the government goal on marine biota protection and management.

Chapter 2

Table 2.4. The adherence of the Indonesian regulatory framework to principles mentioned in International conventions with respect to marine mammal governance.

Management principles	Legislation Item [a]
International Convention for the Regulation of Whaling (ICRW) by IWC [b]	
- Almost all whale species are protected from commercial killing purposes	3,4,5,11,12,16
- Regulates any kind of (human) activities that may threaten the whale species and its stocks	9,13,20,23,24,27,28
- Encourages development of sanctuary areas where whaling activities are strictly prohibited	7-10,14-16, 18,19,21,22,25
- Manages whaling activities, including setting a moratorium on commercial whaling, catch limits for aboriginal subsistence whaling, and managing scientific whaling	N/A
Convention on International Trade in Endangered Species of Wild Flora and Fauna (CITES)	
- Strict regulation of global trafficking of all threatened and endangered species	1-5,11,12,16
Convention on the Conservation of Migratory Species of Wild Animals (CMS) [c]	
- Prohibits taking, hunting, fishing, capturing, harassing, or deliberate killing of migratory species	1-5,11,12,16
- Immediately protects the migratory species of its Appendix I	1-5,11,12,16
- Conserves, restores and ensures sustainable use of migratory animals and their habitats	7-10,14-16, 18,19,21,22,25
- Controls adverse factors for migratory species	9,13,20,23,24,27,28
- Study on identification of migratory species, their range and migration routes	27
- Creates an international cooperation towards the conservation of migratory species	6,9,25
United Nations Convention on the Law of the Sea (UNCLOS)	
- Stresses the importance of and encourages international cooperation for living resources	6,9,25
- As highly migratory species, marine mammals are a conservation target	1-5,11,12,16
Convention on Biological Diversity (CBD) of the United Nations	
- Recognises the traditional dependence of humans on biological resources	7,9,14
- Manages the traditional use of biological resources sustainably	7,9,10,12,15,16
- Establishes a system of protected area-like regions to conserve biological diversity	7-10,14-16, 18,19,21,22,25
- Controls risks associated with the use of biological diversity	9,13,20,23,24,27,28
- Incorporates considerations of biodiversity conservation within national policy-making	All
- Encourages cooperation among parties in all activities regarding biological resources	6,9,25
- Develops action plans for implementing CBD in terms of marine and coastal biodiversity through integrated coastal area management and marine protected areas (Jakarta Mandate)	9,27

[a] See the number of regulation in Table 2.2.
[b] Indonesia is not a member of the International Whaling Commission (IWC).
[c] Indonesia is not a full member of CMS, only as an Agreement-MoU Signatory for marine turtles.

The ratified conventions have a significant bearing on marine mammal governance and protection for Indonesia. CITES reflects a marine mammal protection approach through strictly managing international commercial trade of all threatened and endangered species. UNCLOS provides a comprehensive international legal regime for oceans and seas worldwide; regarding marine mammal management, this convention explicitly encourages international cooperation on marine mammal conservation among ratifying countries. Marine mammals are specifically mentioned as a conservation target. CBD is the parent multilateral treaty on conservation of biodiversity and the sustainable use of its components. Under this convention, marine mammal governance and protection are embraced through several policy items, such as recognition of the dependence of traditional communities on biodiversity, protected area systems, international cooperation, and considering biodiversity conservation within national policy-making.

The two conventions that are not (yet) ratified by Indonesia are the International Convention for the Regulation of Whaling (ICRW 1946) and the Convention on the Conservation of Migratory Species of Wild Animals (CMS 1979). Although ICRW and its commission, IWC (International Whaling Commission), were established earlier than the other conventions regarding marine mammal management, Indonesia still is not a member of IWC. However, the convention is included in this study, since it is heavily related to the IWC issues on traditional hunting practiced by Indonesian locals. Towards CMS, Indonesia has only signed the MoU (Memorandum of Understanding) for marine turtles but has not yet done so for dugongs and cetaceans, migratory species that occur in Indonesia. The degree of adherence of the Indonesian regulatory framework to principles mentioned in International conventions with respect to marine mammal governance showed in Table 2.4.

2.3.1.2. National legal framework on marine mammal protection and management

Twenty eight regulations were found in the national legal framework related to marine mammal protection and management. These regulations cover many aspects of their management including determination of protected species and appropriate uses of the species, establishment of protected area systems, measures to deal with bycatch, marine pollution management, promotion of international cooperation, and development of action plans intended for marine mammal management (Table 2.2).

In the policy mapping (Fig. 2.2), the legislative framework for marine mammal governance falls into three categories: species-specific, site-specific, and other measures (Fig. 2.2). All these regulations are also interrelated as several regulations reflected more than one measure category (Fig. 2.2). For instance, the Government Regulation No.60/2007 that is initially enacted to provide conservation of fish resources (marine mammals are considered as ‘fish’ under this regulation) through stipulation of aquatic conservation areas (site-specific measures), at the same time manages the utilization of fish resources in trading and aquaria (species-specific measures). The mentioned protected fish refer to CITES Appendices species, hence all marine mammals that occur in Indonesia are categorised as protected species (species-specific measures).

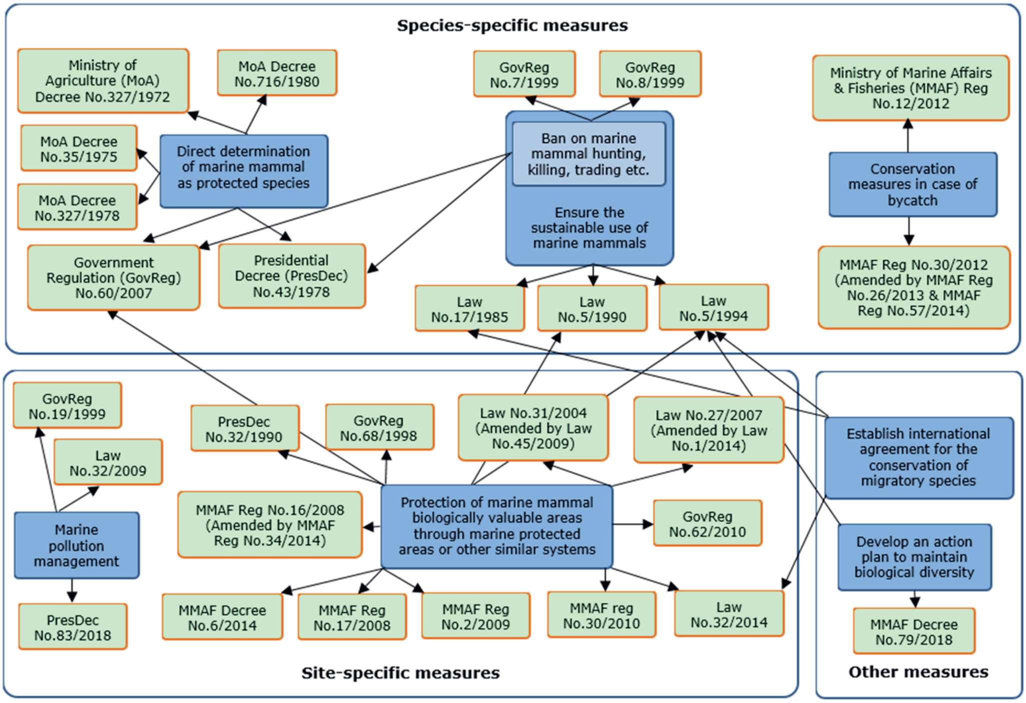

Fig. 2.2. Policy mapping: the interrelation among Indonesian regulations included in this work. Three categories of measures within the regulations are distinguished: species-specific measures, site-specific measures, and other legal options for protecting marine mammals. The content of each regulation is summarised in Table 2.2.

The history of marine mammal protection in Indonesia started with the issuance of the Minister of Agriculture's decree No. 327/1972. This regulation became the first legal basis for the protection of the dugong, one of the marine mammals in Indonesia. Progress on legal frameworks regarding marine mammal governance reveals three different phases (Fig. 2.3, top panel). In the first phase, from 1972 to 1980s, regulations were mainly produced to protect individual species. In the second phase from 1990 onward, the regulations reflected site-specific management dominated by stipulation of regulations for marine protected areas or other similar systems, as well as marine pollution management. The last phase, from 2010 onward, is characterised by a wider marine management approach that is applied in national policy including marine spatial planning and bycatch fishing management.

The Indonesian government extended the protection and management of marine mammals when Law No.1/2014 was issued. According to the regulation, migration paths of marine biota have to be incorporated in Marine Spatial Planning (MSP) through a zoning plan for the coastal areas and small islands (Indonesian:

Rencana Zonasi Wilayah Pesisir dan Pulau-Pulau Kecil, abbreviated as *RZWP3K*). The zoning plan needs to provide protection of habitat and other important areas for marine life and migratory species such as marine mammals. Until 2018, of the 34 provinces in Indonesia, 16 have finalised their MSPs and complemented them with provincial regulations (Table 2.3, Fig. 2.4). The national guidance on incorporation of migratory paths in an MSP, however, is implemented quite differently in the provincial regulations. Among 16 provincial regulations, 14 regulations provide migration corridors (areas or zones) or migration paths (indicative lines) for marine biota of which 12 regulations specifically mention marine mammal biota (Table 2.3).

2.3.1.3. Adherence of Indonesia to international conventions

An examination of the Indonesian legislative framework for marine mammal governance and protection shows that the national management approach mostly reflects the required principles laid down in the main international conventions used in this study (summarised in Table 2.4). They include regulations on determination of protected species, sustainable use of species, global commercial trades on endangered species, protected area establishment, controlling anthropogenic and adverse factors, encouraging global cooperation, and development of an action plan for marine mammal management. The only part of the international legislation that has not yet been integrated in Indonesian legislation relates to whaling activities, particularly traditional subsistence whaling in Indonesia. There is no specific regulation intended to manage this practice.

2.3.2. Institutional arrangements

The development of legal frameworks regarding marine mammal governance was consequently followed by changes in institutional arrangements (Fig. 2.3, bottom panel). This effort has especially involved the creation of new institutions required to handle specific tasks that previously were not well delivered. Although the institutions discussed here are mostly responsible for broader marine management, they also are eligible for marine mammal management.

In 1972, the Department[1] of Agriculture (DoA) of Indonesia issued Ministerial Decree No. 327/1972, the first regulation in Indonesia to protect marine mammals. At that time, the DoA was authorised by law to protect endangered animals in Indonesia since a specific department was not established yet. The DoA had two subordinate agencies named the Directorate General (DG) of Forestry and the Directorate General (DG) of Fisheries, which were appointed to be the implementer of wildlife conservation in Indonesia. The main task of these two Directorate Generals related to marine mammal conservation is to maintain the diversity of protected species so that

[1] Before 2009, the Indonesian government used word ‘Department’ to name its ministries.

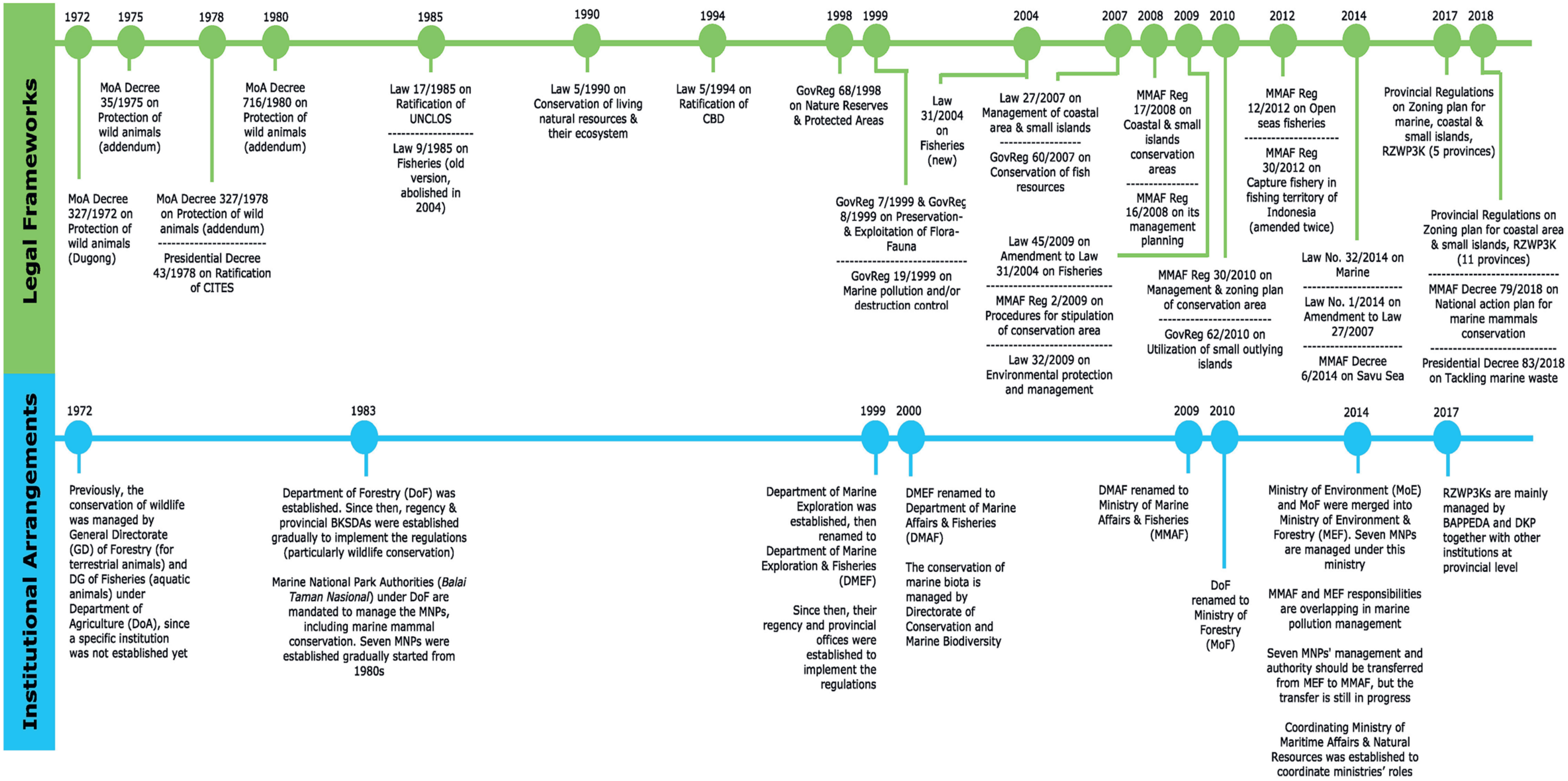

Fig. 2.3. Timeline of instalment of legal frameworks and institutional arrangements regarding marine mammal governance in Indonesia. MoA, Minister of Agriculture; GovReg, Government Regulation; *RZWP3K*, *Rencana Zonasi Wilayah Pesisir dan Pulau-Pulau Kecil* (A zoning plan for the coastal areas & small islands); *BKSDA*, *Balai Konservasi Sumber Daya Alam* (Agency for natural resources conservation); *BAPPEDA*, *Badan Perencanaan Pembangunan Daerah* (Agency for regional development planning), *DKP*, *Dinas Kelautan dan Perikanan* (Office for marine affairs and fisheries).

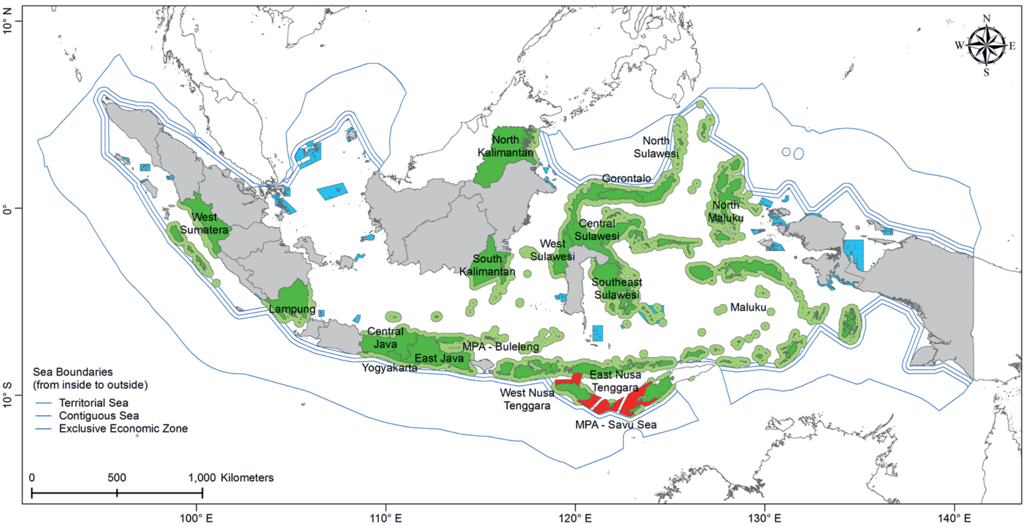

Fig. 2.4. Spatial gaps in jurisdiction: Until 2018, among 34 provinces (grey) in Indonesia, 16 provinces (green) already have their own marine spatial planning (*RZWP3K*, light green) that provide different benefits for marine mammals (see Table 2.3). Of 177 MPAs (blue), only two MPAs (red) are specifically designed for marine mammals.

they are prevented from extinction. In 1983, DG of Forestry became a stand-alone department; the Department of Forestry (DoF). Since 1978, regency and provincial agencies for natural resources conservation (Indonesian: *Balai Konservasi Sumber Daya Alam*, abbreviated as *BKSDA*) have also been established gradually in order to implement the regulations on wildlife conservation more locally.

In 1990, the Indonesian government issued Law No. 5/1990 concerning conservation of living resources and their ecosystems and appointed the DoF to be the implementer of the law. Through this law, the government introduced the concept of nature reserve areas, including the stipulation of marine conservation areas. The Directorate General of Forest Conservation and Nature Preservation (now called DG of Natural Resource Conservation and Ecosystems) is an institution under the DoF which is appointed to implement regulations relating to the protection of wildlife in general and management of conservation areas. Marine National Park (MNP) Authorities (Indonesian: *Balai Taman Nasional*) under the DoF are mandated to manage the MNPs, including marine mammal conservation. Seven MNPs were then established gradually from the 1980s onwards. The DoF was renamed the Ministry of Forestry (MoF) in 2010.

The Department of Marine Exploration was established in 1999, then renamed the Department of Marine Exploration and Fisheries. It once again changed its name to the Department of Marine Affairs and Fisheries in 2000, and got its current name, the Ministry of Marine Affairs and Fisheries (MMAF), in 2009. This change in ministerial nomenclature does not only concern the name but also denotes the process and the consequences for the tasks and responsibilities, thus showing the changing priorities of the government. The conservation of marine biota is managed by the Directorate of Conservation and Marine Biodiversity under the MMAF. Since 1999, marine and fisheries offices of the MMAF have gradually been established in all regencies and provinces to implement the regulations. Since then, conflicts between the MoF and the MMAF began to emerge mainly on authority dualism on aquatic conservation area management. Based on Presidential Decree No. 102/2001, the MMAF claimed that it was responsible for the marine life conservation program, including marine mammals, and for managing marine conservation areas. The MMAF requested the MoF to hand over the management of seven marine national parks, namely: Kepulauan Seribu, Karimun Jawa, Taka Bonerate, Wakatobi, Togean, Bunaken, and Teluk Cendrawasih. The MoF, however, did not agree with this.

In 2014, the MoF was merged with the Ministry of Environment to become the Ministry of Environment and Forestry (MEF). The debated management of seven MNPs were then managed under this ministry; the MEF refused the request from MMAF and argued that their mandate to manage marine conservation areas had never been cancelled. A new Coordinating Ministry of Maritime Affairs and Natural Resources was established in the same year mainly to coordinate ministries' roles, and is expected to resolve those of the MEF and MMAF. According to Law No.1/2014, the management and authority of the seven MNPs should be transferred from MEF to MMAF, but the transfer process has stalled. The overlapping jurisdiction between MMAF and MEF on MNP management is still unresolved up to now, which hampers good management. Since October 2019, the name of the Coordinating Ministry changed again and now is Coordinating Ministry of Maritime Affairs and Investment. The name change suggests a change in priority.

Another overlap among the responsibilities of the MMAF and the MEF with respect to marine conservation issues regards marine pollution management. The MEF aims to preserve the marine environment, including issues of pollution and contamination, but so does the MMAF. The overlaps should be disentangled to be able to improve the efficiency of marine mammal management in Indonesia. Collaboration between two ministries is necessary, as the MEF ministry focuses on pollution (including hazardous materials and plastics) and environmental impact assessments, optimising the MMAF task on marine management.

The Indonesian government also issued Law No. 23/2014 concerning regional government, which together with Law No.1/2014, mandates the provincial government to stipulate a zoning plan for the coastal areas and small islands (RZWP3K) in their areas. A zoning plan aims to protect marine habitats and specific important areas (for instance migratory paths, as well as spawning and feeding areas) for marine life and migratory species such as marine mammals. RZWP3Ks are mainly managed by two provincial offices: the agency for regional development planning

(Indonesian: *Badan Perencanaan Pembangunan Daerah, BAPPEDA Provinsi*) and the regional agency for marine affairs and fisheries (Indonesian: *Dinas Kelautan dan Perikanan, DKP Provinsi*) together with other institutions at provincial level.

2.3.3. Policies

The government policy for marine mammal protection can be extracted from existing regulations and categorised into three principal groups: species-specific policies (three policies), site-specific policies (two policies), and other policies (two policies). In total, there are seven policies (Fig. 2.5), elaborated as follows.

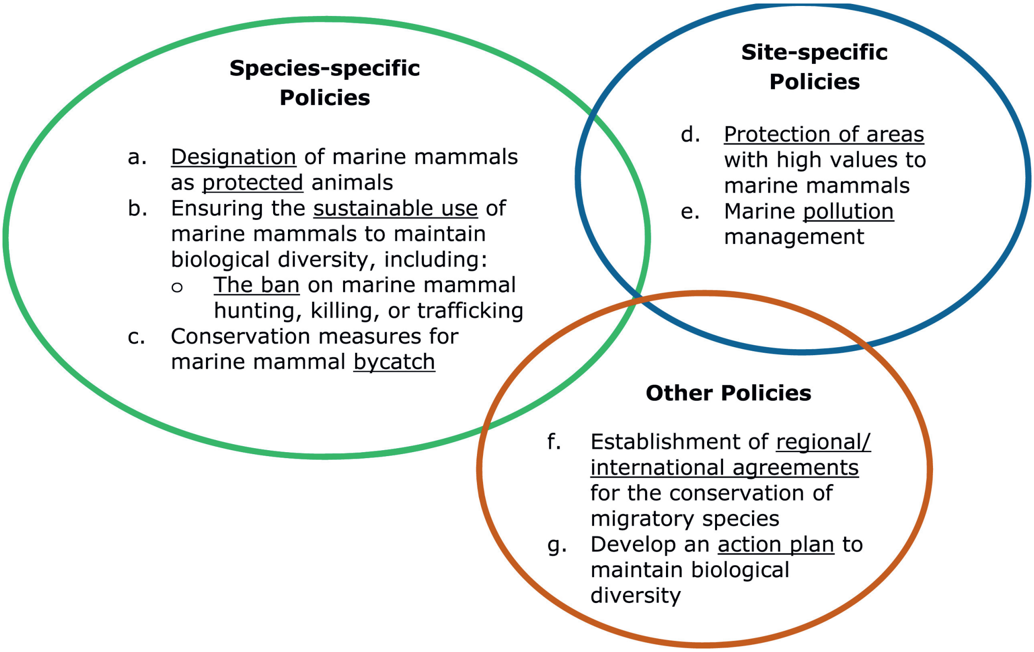

Fig. 2.5. Policies for marine mammal governance and protection condensed from the existing national legal framework.

2.3.3.1. Designation of marine mammals as protected animals

The Indonesian government started to apply policy for marine mammal protection by direct stipulation of endangered and vulnerable species as protected biota through enactment of several regulations. Its origin goes back to 1972 when the dugong was assigned the status of a protected wild animal. Freshwater- and marine dolphins were also declared as protected biota in 1975, followed by several whale species in 1978.

A large number of marine mammal species became protected after the Indonesian government ratified CITES in 1978. Protected species, including all marine mammals which occur in Indonesian waters, are listed in Appendix I and Appendix II of the convention. All whales that were later found in Indonesian waters are also listed as protected wild animals in the addendum in 1980. The protected animal averment occurred in 2007, when Government Regulation No.60/2007 was issued. The regulation protects fish as referred to in the CITES Appendices, and these include all marine mammals which occur in Indonesia. So in total, 35 marine mammal species are protected, 12 species referred to the Appendix I and 23 species in the Appendix II.

2.3.3.2. Ensuring the sustainable use of marine mammal to maintain biological diversity

Indonesia ratified the United Nations Convention on the Law of the Sea (UNCLOS) of 1982 through enactment of Law No.17/1985 originally to strengthen its position as an archipelago state. However, since the convention was fully ratified, all contents of the convention became a legal basis for Indonesia, including the sustainable use of biodiversity. It mentions that as a ratifying state, Indonesia has the sovereign right to explore, exploit, and manage biodiversity in its territorial sea, exclusive economic zone, and high seas. The law also explicitly stresses the importance of marine mammal conservation. Therefore, the right to exploit their biodiversity can only be done in a sustainable manner.

Sustainable use of biodiversity is regulated in Law No.5/1990. Marine mammal utilization is included within this regulation, since it regulates the sustainable use of biological natural resources and their ecosystems. The uses of the species that are forbidden by this law include those explained below (*in the italic subsection*). Fines and penalties are set for violating this law.

The most comprehensive regulation on conservation and sustainable use of biological diversity is Law No.5/1994 on Ratification of the CBD. Indonesia ratified the CBD, because it would recognise traditional whale hunting in Indonesia. As a CBD member, Indonesia should manage whale hunting sustainably. The CBD also suggests that country members control risks for biodiversity associated with its use.

The ban or strict regulation on marine mammal hunting, killing, or trafficking

Strict regulation on commercial trading on endangered species was set by the Indonesian government when the Presidential Decree No.43/1978 on Ratification of CITES was enacted. As all marine mammal species which occur in Indonesian waters are listed in the CITES Appendices I and II, they became subject of this regulation.

Two derivative regulations of Law No.5/1990 underlined the direction towards a ban on the hunting, killing, or trafficking of protected species. The first regulation is Government Regulation No.7/1999 that prohibits the killing and trading of protected animals, including all marine mammals in Indonesia. The second one is Government Regulation No.8/1999 that applied strict regulation for protected wildlife from being captured, hunted, traded, exchanged or raised for pleasure.

Under Government Regulation No. 60/2007, marine mammals are considered as 'fish'. The regulation divided fish into protected and unprotected fish. Since protected fish mentioned in this regulation refer to CITES Appendices species, all marine mammals occurring in Indonesia belong to protected 'fish'. Strict regulations are applied in utilization of fish resources, including those for trading, aquaria, and exchange.

2.3.3.3. Conservation measures for marine mammal bycatch

Marine mammals easily get entangled in fishing nets. Therefore, the Indonesian government, through the MMAF, has set two regulations to minimise marine mammal bycatch. The first regulation is MMAF Regulation No. 12/2012 on Open seas fisheries. The second regulation is MMAF Regulation No. 30/2012 on Capture fisheries in fishing territory of Indonesia, that has since been amended twice through MMAF Regulation No. 26/2013 and MMAF Regulation No. 57/2014. Both regulations demand any fishing vessel that make unintentional bycatch of marine mammals in tuna or other pelagic fishing has to release the animals alive. The mammalian bycatch should also be reported to the port authority for documentation purposes.

2.3.3.4. Protection of areas of high value to marine mammals

This is the most important policy for marine mammal protection management in Indonesia. A large number of regulations fall in this policy category. Although all these regulations don't explicitly state the protection of marine mammals, it highlights the importance of migration corridors and habitat protection during establishment of marine conservation areas, hence offering protection to marine mammals.

As a response to contemporary issues on site-specific management for biodiversity in the early 1990s, the Indonesian government enacted Presidential Decree No.32/1990 that asserts the necessity of the establishment of protected areas. Implementation of conservation of marine and coastal biological diversity through marine protected areas or other protected area-like systems was mentioned in Law No.5/1994. Law No.5/1990 and its derivative regulation, Government Regulation No.68/1998, already stated the important of in-situ conservation of biodiversity through establishment of nature reserves and nature protected areas.

Two regulations were issued by the government to support the fishery resources management led by the MMAF: Law No. 31/2004 (later amended by Law No. 45/2009) and Government Regulation No. 60/2007. Under these regulations, marine mammals are grouped as 'fish', which contradicts the scientific definition and the definition used by the MEF (e.g., Government Regulation No. 7/1999). As a derivative regulation of Law 31/2004, Government Regulation No. 60/2007 categorised four forms of aquatic[2] conservation areas: aquatic national park, aquatic tourism park, aquatic nature reserve, and fishery sanctuary. Stipulation of aquatic conservation areas have to take ecological aspects into account including migration corridors of marine biota.

Law No. 27/2007, later amended by Law No. 1/2014, stands out in coastal and small island conservation by protecting migration corridors and habitats of marine biota in developing a zoning plan for the coastal areas and small islands (RZWP3K). Its derivative regulation, MMAF Regulation No. 16/2008 (later amended by MMAF Regulation No. 34/2014) mentions that marine biota migration pathways are one of the sea lanes that should be included in RZWP3K.

Through MMAF Regulation No. 17/2008, four types of coastal and small island conservation areas are defined: coastal sanctuary, small islands sanctuary, coastal park, and small island park. The core zone must be defined in the design of each area, and include a migratory corridor for marine biota. Two other regulations, MMAF Regulation No. 2/2009 and MMAF Regulation No. 30/2010, also emphasise the importance of migratory corridors in the stipulation of aquatic conservation areas.

The marine conservation areas also need to be established in other types of seas, including small outlying island waters and high seas. Government Regulation No.62/2010 is the base for assigning outlying islands as conservation areas, while Law No. 32/2014 mandates the government to protect the marine environment and migratory species through marine conservation in high seas.

To date, more than 20 million hectares of marine conservation areas or MPAs have been established by the Indonesian government [84]. This achievement is the fulfilment of the government commitment as declared during COP-CBD in Brazil in 2006 to establish and manage 10 million hectares of MPAs by 2010, that then was readjusted to be 20 million hectares by 2020 during the World Ocean Conference 2009 [114]. Among 177 MPAs in Indonesia [84], only two MPAs are intentionally designed for marine mammals, namely Buleleng and Savu Sea (Fig. 2.4). MMAF Decree No.6/2014 is a legal basis for the management plan and zoning of Savu Sea Marine National Park that manages marine mammal populations through regulation of fishing practices, shipping and mining activities. Migration seasons and corridors are also considered.

2.3.3.5. Marine pollution management

To control marine pollution and contamination, Government Regulation No. 19/1999 has been set up to regulate activities that cause marine pollution and destruction. Law No.32/2009 on Environmental Protection and Management

[2] Three different terms are used in this study: aquatic conservation area, marine conservation area, and marine protected area (MPA). 'Aquatic' includes freshwater and marine, but here mainly refers to marine. MPA is an umbrella term, under which all conservation areas fall.

(replacing the old version, Law No.23/1997) contributes to marine mammal management by protecting natural habitats and regulating pollution that can negatively impact the marine ecosystem.

Recently, marine pollution with waste plastics has become a major threat for marine biota, including marine mammals. To resolve the marine waste problem, particularly related to plastics, Presidential Decree No. 83/2018 has been issued. This document describes the detailed strategy, program, activities, and institutions that are responsible for reducing marine waste, including plastics, for the period 2018–2025. Noise pollution resulted from e.g., seismic activities in ocean, however, is not mentioned in any Indonesian regulation.

2.3.3.6. Establishment of regional/international agreements for the conservation of migratory species

Important for successful management of marine migratory species is regional and international agreement and cooperation. This is stimulated in the national legal framework and there are three regulations that underline this. Law No.17/1985 on Ratification of UNCLOS encourages international cooperation for marine mammal conservation for all ratifying countries. Collaboration among states in all activities regarding biological resources is also mentioned as being important in Law No.5/1994 on Ratification of the CBD. Lastly, the enactment of Law No. 32/2014 also benefits marine mammal management and promotes international cooperation in the field of marine resource conservation and management.

2.3.3.7. Develop an action plan to maintain biological diversity

The opportunity to develop a specific action plan to protect biodiversity is included at a national level policy through enactment of Law No.5/1994 that ratified the CBD. The CBD followed up with the Jakarta Mandate [235], which suggests developing action plans intended to implement the CBD principles on protection of marine and coastal biodiversity through integrated coastal area management and marine protected areas.

A purposeful action plan to conserve marine mammals has recently been launched by the Indonesian government through enactment of MMAF Decree No.79/2018 on a National Action Plan for marine mammal conservation for the period of 2018–2022. The marine mammals mentioned in this decree are dugongs, whales and dolphins. This action plan is a comprehensive, structured, and detailed guidance that includes all aspects needed for conserving marine mammals, including a comprehensive strategy and implementation and enforcement mechanisms. The action plan highlights seven main points for cetacean conservation i.e., (i) research on ecological and socio-economic-cultural aspects of cetaceans, (ii) building of a cetacean database and information system, (iii) reduction of the mortality rates from fishing and ship strikes, (iv) identification and protection of critical cetacean habitat (e.g., migration corridors) as conservation areas, (v) regulation and modelling the potential economic value of cetaceans, (vi) capacity building and strategic partnership for registration of cetacean stranding, and (vii) regulation of the negative effects of noise and coastal development on cetaceans.

2.4. Discussion

Strong regulatory capacity is required in performing environmental governance in general [236], as well as in effective management of marine mammal biodiversity. Within the current Indonesian legislative framework, several items of legislation already are in place as important cornerstones for marine mammal protection and management. The extensive marine mammal protection approach covers two aspects. Firstly, a species-centred management approach designating marine mammals as protected biota including measures for strictly sustainable use of these species and development of action plans for marine mammal management. Secondly, wider marine management, including marine protected areas, measures to tackle bycatch, and significant international cooperation. Although the legal basis currently exists for marine mammal protection in Indonesia, the practical actions derived from these regulations are still unclear. Implementation and consequent enforcement of the regulations are also still underdeveloped.

Until now, more than 20 million hectares of marine conservation areas or MPAs have been established by the Indonesian government. However, among these 177 MPAs, only two MPAs have been formally designated for marine mammals, i.e., Buleleng [237] and Savu Sea Marine National Park [53]. This demonstrates the urgency for increased real protection of areas for marine mammals. Site-based conservation such as via MPAs can be effective in addressing threats to marine mammals from e.g., fisheries or tourism. It is, however, difficult to design an MPA of a large enough functional scale or a smart network of smaller MPAs [12]. MPA alone is not always sufficient to guarantee protection for the marine mammal species because of range expansion of the animals [238] or inadequate management [113]. The zoning systems set within an MPA are not always intentionally dedicated for marine mammal protection.

To reduce fisheries impact on marine mammals, Indonesian regulations demand fishing vessels operating in Indonesian waters take proper conservation measures to reduce the number and effect of bycatch of marine mammals. A recent study showed that marine mammals are mostly acquired alive in Indonesian tuna longline fisheries bycatch and the hook rate for dolphin and whale bycatch was relatively low, around 0.002 per thousand hooks [239], although other scientists predicted much higher numbers [54]. Still, in the Mahakam River, Kalimantan, bycatch appears to be the major human cause of dolphin mortality, since use of bycatch-sensitive fishing gear is highly prevalent (85%) [240].

Marine waste, especially lost fishing gear, is a major threat to marine species, including marine mammals [241–244]. Marine plastics are often found in the stomachs of marine animals including cetaceans [241,245]. The government of Indonesia recognises this threat and intended to reduce it by enacting regulations focusing on marine pollution management (Government Regulation No. 19/1999 and Law No.32/2009). The effect, unfortunately, is still limited and given the extent of the problem in Indonesia, Presidential Decree No. 83/2018 has been issued to accelerate the implementation and enforcement of a marine waste reduction program. This program is followed by many local governments, to name a few: Bali province [246], Padang city in Sumatera [247], and Samarinda city in Kalimantan [248]. These local regulations for instance in Bali, however, were questioned by some plastic industries and they pushed the government to cancel the regulation [249]. However, there was also civic movement to retain the regulation [250] and the demand has been approved by the government. Other type of pollution that negatively affects marine mammal life is underwater noise resulted from e.g., seismic activities [251,252] during offshore mining, oil and gas exploration. However, until now there is no dedicated regulation in Indonesia to regulate this issue.

The growing human population puts increased pressure on natural resources and coastal marine waters which as a consequence are becoming increasingly degraded. Unregulated anthropogenic modifications and environmental degradation cause dramatic declines in habitat quality and food availability for these marine biota [37] which is aggravated by domestic and foreign (over)fishing. Although the Indonesian government has also set regulations governing foreign fishing activities, there is still illegal, unregulated and unreported (IUU) fishing going on [55]. The effects of these activities for marine mammal protection are still unknown.

So far, Indonesia has not yet introduced codes of practice for whale and dolphin watching. The codes of practice should regulate the minimum approach distance to the animals, the maximum number of boats around the cetaceans, the maximum time allowed around the animals, and the speed and angle of approaching the animals. Such guidelines are urgently needed to support sustainability of marine mammal watching tourism [253]. The improvement of regulation on qualification standards of ex-situ conservation for marine mammals (such as aquaria) is also needed. Both should be part of specific action plan within the current legal framework for marine mammal protection management.

Some regulations that are counter-productive to marine mammal conservation are identified. For instance, according to the Fisheries Law 31/2004 (Amended by Law 45/2009), marine mammals are considered 'fish' (Article 1 clause 4, and Explanation section of Article 7 clause 5). Labelling marine mammals as 'fish' may lead to the misconception that those species are available for harvesting. However, Government Regulation No. 7/1999 clearly states in its appendix that all marine mammals are protected species, and thus should not be caught, killed or traded. Article 7 clause 1 of the Law 31/2004 also mentions that in order to support the fishery resources management policy, protected fish species and aquatic conservation areas need to be stipulated. Since marine mammals are considered as fish, the fishery conservation and stipulation of aquatic conservation areas would on the other hand benefit marine mammals as well.

The Indonesian government shows a high commitment for marine biota protection and marine management in general. The government, hitherto, is open to global initiatives by adopting relevant international conventions into its national legal framework. Among five global conventions, three have been fully ratified by Indonesia to fill the gaps in its national legal framework. The examination of the current legal framework shows that the national management approach mostly reflects the required principles agreed in the international conventions. Only the ICRW is not ratified by Indonesia because in the past it was believed that this would pose problems for the traditional hunting still practiced by Lamalera locals in the Savu Sea. However, the traditional whaling conducted at Lamalera would probably fit within the definition of 'aboriginal subsistence whaling' as permitted and managed by the IWC, a matter that deserves to be fully explored. The Indonesian government has no formal written position with respect to traditional whale hunting which is a deficiency of the current legal framework that needs to be repaired by providing dedicated regulation to address this problem. However, several national regulations acknowledge and respect the rights of traditional communalities e.g., on environmental protection and management (Law No. 23/2014 on Local Government, Article 15 clause 1 and Appendix I.K) and capture fisheries management (Law No. 45/2009 on Fisheries, Article 6 clause 2). The uncertainty about the sustainability of this hunting, however, is still questioned and possibly leads to international concerns. In another whaling village nearby Lamalera, i.e., the village of Lamakera in Solor Island (west of Lembata Island where Lamalera is located) whaling is also rooted in tradition [55]. Its practice, however, has shifted from subsistence to commercial whaling. Such shifting from small scale subsistence to larger scale commercial whaling with much greater potential impact on whale populations, requires differentiated conservation management.

The whaling prohibition in the Savu Sea would introduce problems for the traditional whale hunters, including eroding their food security [55]. For Lamalera people, whale hunting is an integral part of their socio-cultural system. The prohibition of whale hunting would bring about serious socio-cultural consequences to the community not only internally but also in relation to neighbouring communities which the Lamalera people barter their whale meat with other commodities. The

Indonesian government needs to conduct a comprehensive study of the marine mammal populations in the Savu Sea, and the sustainability of the traditional whaling practices.

Joining the IWC would provide more benefits for Indonesia since IWC can support the assessment of traditional whale hunting sustainability and other benefits beyond whaling, including management of whale watching, ship strikes, marine noise, chemical pollution, marine debris, cetacean conservation, and climate change issues [234]. International as well as regional cooperation is needed to strengthen the marine mammal protection effort. The framework of multilateral environmental agreements such as CBD and CMS, as well as a potential agreement through UNCLOS is very promising. Indonesia is a full member of the CBD and UNCLOS, but signed the MoU of the CMS only for sea turtles. Although dugong and cetaceans widely occur in Indonesian water, Indonesia did not sign the CMS MoU for these migratory species. It would be strategic for Indonesia to become a full member of the CMS, as the CMS can assist Indonesia in management of and research into marine mammals. Joining the CMS would facilitate regional collaboration with Australia and other countries that have been conducting extensive studies on marine mammals, including the species targeted by whale hunters [55].

Although regional collaborations that can strengthen research on marine mammals in Southeast Asia and adjacent regions have existed for more than a decade, those initiatives are not yet optimised. Indonesia has been actively involved in the establishment and management of the Coral Triangle Initiative (CTI) along with Malaysia, the Philippines, Timor Leste, Papua New Guinea and Solomon Islands. The CTI aims to, among others, improve the status of threatened species, including marine mammals [80]. However, there is insufficient evidence to date that the CTI has dedicated optimum efforts in addressing issues related to marine mammals. Another regional initiative worth mentioning is ASEAN (The Association of Southeast Asian Nations). More than a decade ago, the Southeast Asian Fisheries Development Centre (SEAFDEC) has reviewed cetacean studies in SE Asian Waters [81]. In early 2019, the ASEAN Science, Technology and Innovation Fund (ASTIF) provided some funding to conduct a workshop in Malaysia to assess the conservation of marine mammals and other endangered marine organisms. This workshop suggested the creation of a marine mammal (or marine megafauna) working group within ASEAN to address issues related to these taxa.

An important additional aspect of marine mammal protection was issued by the Indonesian government by designating a marine mammal migration corridor or path as a lane in a provincial marine spatial planning (RZWP3K) establishment [230]. It is, however, not yet clear how to determine the lane correctly in the zoning plan. Our review of 16 provincial regulations regarding the RZWP3K shows that 14 provide migration corridors or migration paths for marine biota of which 12 specifically mention marine mammal species. There are some additional aspects mentioned in each regulation such as regulate vessel speed when passing the migration paths, regulate type of fishing gears or restrict human activities in the migration paths, and synchronise the migration paths with other marine spatial uses (Table 2.3). This was the case where national general guidance on incorporation of migratory paths in an MSP was implemented. Support from the national level government including a clear standard on how to incorporate these aspects into the provincial zoning planning development is needed to optimise its implementation.

The recent national action plan for marine mammal conservation that has been issued by the Indonesian government [231] is very comprehensive, structured, and detailed, and provides a general strategy as well as a step by step implementation mechanism to conserve dugongs, whales and dolphins in Indonesia. The main aspects include research capacity building, database development, anthropogenic threat reduction on marine mammals, stranding network corroboration, and marine mammal conservation integration into marine spatial planning. The action plan also mentioned the importance of networking and management of marine mammal stranding [54,194]. Such a network has already been established by volunteers; the network has contributed to resolving many stranding events in Indonesia since 2002. Recently, the DG of Marine Spatial Management of the MMAF is assigned responsibility for coordinating marine mammal stranding events, however, the legal basis for the stranding network involving communities is not available. The role of this voluntary network in doing so is relevant to what Ref. [254] reported that community-based organizations play critical assisting roles in a governance system, even if they have not been stipulated public roles in an official way.

The implementation of such regulation is unfortunately still constrained by institutional arrangements that are characterised by a lack of sufficient sectoral coordination, resulting in uncertainty and inconsistency in law enforcement, authority dualism as well as institutional conflicts. The jurisdictional overlaps and unclear mandates in current wildlife conservation and broader marine protected area management between MEF and MMAF still is unresolved. The MMAF claims that its duties and responsibilities pertain to the marine life conservation program and marine conservation area management. Therefore, the MMAF requested that the MEF hand over the management of seven marine national parks. Conversely, the MEF refuses the request from MMAF and argues that their mandate to manage marine conservation areas had not been abolished [232]. A successful marine mammal protection requires effective coordination and full cooperation of all involved government agencies in marine life and marine conservation area management as well as national-provincial levels [255,256]. Such an effort to resolve the overlap in mandates could be led by the Coordinating Ministry of Maritime Affairs and Investment, since its main task is to coordinate the ministries' roles. Another responsibility overlap between the MMAF and the MEF regards marine pollution management could be solved by encouraging a collaboration between both ministries to optimise marine management. The presence of different institutions working on the same domain is pivotal in natural resource governance [257].

This paper does not analyse the effectiveness of the existing provisions due to limited data availability. For example, no information is available on how many prosecutions have been made from violating any of the provisions or the degree of cetacean population declines or recoveries or the impact of the threats on cetacean populations (e.g., degree of bycatch), as well as the extend of enforcement of the regulations. Such data need to be gathered in the future to be able to assess the effectiveness of the provisions. Examining the systems' effectiveness is outside of the scope of the current study, and we strongly support that this should be addressed in the near future. The problems with cetacean conservation are not only the legal gaps but also the discrepancy between the formal legal construction and the reality of enforcement on the ground. This is, one among many factors, because the legal formal construction is driven more by biological-ecological and legal considerations than by human dimension considerations (e.g., community perspective, interests and participation that are often neglected).

2.5. Conclusions and recommended steps

The current Indonesian legislation provides a good legal basis to protect and manage its marine mammals. However, the practical actions derived from the regulations as well as problems with implementation and enforcement of the regulations are not yet well enough developed to provide true protection of the animals in their natural habitats.

Considering the lack of information on the sustainability of Indonesian whale hunting, which is considered important to the local people, it is urgent to provide the science that can underpin the sustainability of traditional whale hunting and resolve the complex IWC-related issue. Continuing research on occurrence and population status, migration corridors, critical habitats of marine mammals as well as anthropogenic threats in Indonesia is also needed. Research on the socio-cultural importance of such traditions is important, because governance should be based on biological and ecological factors and also socio-cultural considerations.

Becoming a full member of the CMS and the IWC will further strengthen the conservation management of marine mammals in Indonesia, a country that is widely known as a range state of the migratory species and still practices subsistence whale hunting. Joining the CMS would facilitate regional collaborations on marine mammal research. The IWC can support the assessment of the traditional whaling sustainability and other benefits beyond whaling (e.g., best practices in cetacean watching tourism and bycatch reduction).

Our review has revealed some urgent-yet-lacking policies in the current legal framework for marine mammal protection effort in Indonesia, such as regulations intended to govern traditional whale hunting that takes socio-cultural issues into account, the introduction of a code of conduct for marine mammal watching tourism, standards for aquaria, and the legal basis for marine mammal stranding network as well as for regulating underwater noise pollution. Establishing a mechanism for cross-institutional coordination is also needed to resolve lacking and/or overlapping jurisdiction among institutions and levels of governance. An adequate and appropriate legal framework and sufficient institutional arrangements and enforcement at the appropriate governance levels will ameliorate and strengthen marine mammal governance and protection in Indonesia.

Conflicts of interest

The authors declare no conflict of interest regarding the results presented in this paper.

Acknowledgements

This work was financially supported by Indonesia Endowment Fund for Education (LPDP) Scholarship from Ministry of Finance of The Republic of Indonesia for the first author [contract number: PRJ-482/LPDP.3/2017]. The authors would like to thank Yitno Suprapto for the preliminary study, Abigail Muscat for proof reading and the anonymous reviewers who helped to improve the quality of this manuscript.

Supplementary information

Supplementary materials of this article can be downloaded at https://ars.els-cdn.com/content/image/1-s2.0-S0308597X19304397-mmc2.docx.

"All models are wrong, but some are useful."

George E. P. Box

Chapter 3

A treasure from the past: Former sperm whale distribution in Indonesian waters unveiled using distribution models and historical whaling data

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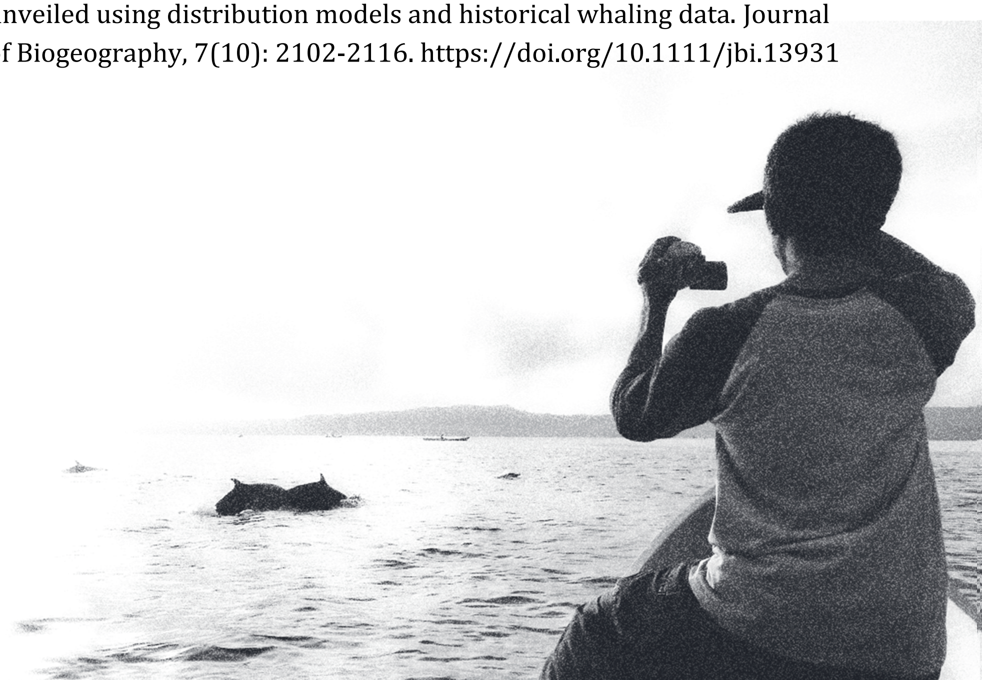
Published as: A. Sahri, M.I.H. Putra, P.L.K. Mustika, A.J. Murk. (2020). A treasure from the past: Former sperm whale distribution in Indonesian waters unveiled using distribution models and historical whaling data. Journal of Biogeography, 7(10): 2102-2116. https://doi.org/10.1111/jbi.13931



Abstract

<u>Aim</u>: This study is the first in Indonesia to assess historical sperm whale (*Physeter macrocephalus*) seasonal distributions by combining historical whaling data with environmental factors associated with sperm whale habitat preferences. As current records of whale occurrence covering the whole of Indonesian waters are incomplete, we used historical whaling data summarised by Charles Haskins Townsend in 1935 to model its potential distribution for each season.

<u>Location</u>: Indonesian waters (92-143E, 9N-14S).

<u>Taxa</u>: Sperm whale (*P. macrocephalus*).

<u>Methods</u>: We used a presence-only habitat model – Maximum Entropy (Maxent) –, and a presence–pseudo-absence method – generalised additive model (GAM) – with nine submerged topographic variables to predict historical seasonal distributions.

<u>Results</u>: Both Maxent and GAM predict similar potential distribution which align closely with the whaling data. The results indicate that in four areas in the eastern part of Indonesia, no seasonal differences occurred in sperm whale distribution, while noticeable seasonal differences were indicated in other areas. The key parameters that characterise sperm whale habitat in both models were distance to coast, distance to −1,000 and −5,000 m isobaths, and submarine key features such as trough and trench.

<u>Main conclusions</u>: The historical catch data of this species can be used to describe the historical species distribution and provide a baseline to assess present distribution, prioritise current research and monitoring and recommend future data collection. Our models also predict distributions that are significantly larger than the ones occupied by sperm whales nowadays, another example of a shifting baseline. Our study demonstrates the benefits of incorporating historical whaling data into habitat models for ecological investigation and to inform conservation efforts for cetaceans.

Keywords: cetacean, conservation management, generalised additive model, historical whaling data, Maxent, species distribution model, sperm whale

3.1. Introduction

Comprehensive knowledge on where marine animals occur, and which characteristics determine their habitat preferences, is important in understanding the ecology of the species and guiding appropriate conservation and management efforts [13,14]. However, animal occurrence data are deficient for many marine species [185] in many regions [258]. For instance, records of cetacean occurrence in Indonesian waters are lacking. This can be attributed to the high logistical costs of conducting expansive surveys [13,186,187]. Historical data are therefore an interesting alternative to consider [187,197,198]. It could even serve to demonstrate shifting baselines in species densities caused by historical factors such as intensive exploitation [29].

Sperm whales (*Physeter macrocephalus*) were hunted extensively across all oceans for two centuries during the Yankee whaling era [31], when females were the focus on tropical grounds [259,260]. Males were preferred by modern whalers for their larger body size [187]. This difference in targeting led to a sex ratio imbalance that may have limited population recovery ever since [31,199]. Sperm whale recovery was also hindered by whaling throughout the last century, some of it illegal and poorly documented [202]. This species is now listed as ‘vulnerable’ under the IUCN Red List of Endangered Species [261].

The long history of the exploitation of sperm whales provides rough information on their past distribution. In 1935, Charles Haskins Townsend published four global charts from the information recorded in American whaling logbooks and journals between 1761 and 1920. The charts show where and in what month American sail whalers captured a total of 36,909 sperm whales globally. Of the five species for which Townsend published charts, only the sperm whale was reported to be captured in large numbers in equatorial Indonesian waters (Fig. 3.1), with a ratio of 79:1 compared to humpback whales. The extensive global analysis published by Townsend [78] reveals three priority whaling grounds in the Indonesian archipelago: the Molucca Passage, the Celebes Sea and the Sulu Sea Grounds (Fig. 3.1).

Townsend's hand plotting of catch points, however, creates difficulties for interpretation [202], and efforts are needed to relate the fragmented catch points to environmental factors in order to assess the continuous surface distribution of the species. In Indonesian waters, Townsend mentions three whaling grounds across the archipelago, with all sperm whales caught outside them referred to as stragglers. The West Banda Sea is not mentioned, even though abundant sperm whale captures were reported there (Fig. 3.1). Townsend did report a seasonal oscillation of sperm whales between the northern and southern latitude. For a better interpretation of the historical data and to assess the full former distribution of sperm whales, habitat modelling can be applied. This approach could also help to indicate seasonal migration between habitats in the past by analysing whale presence across the different seasons.

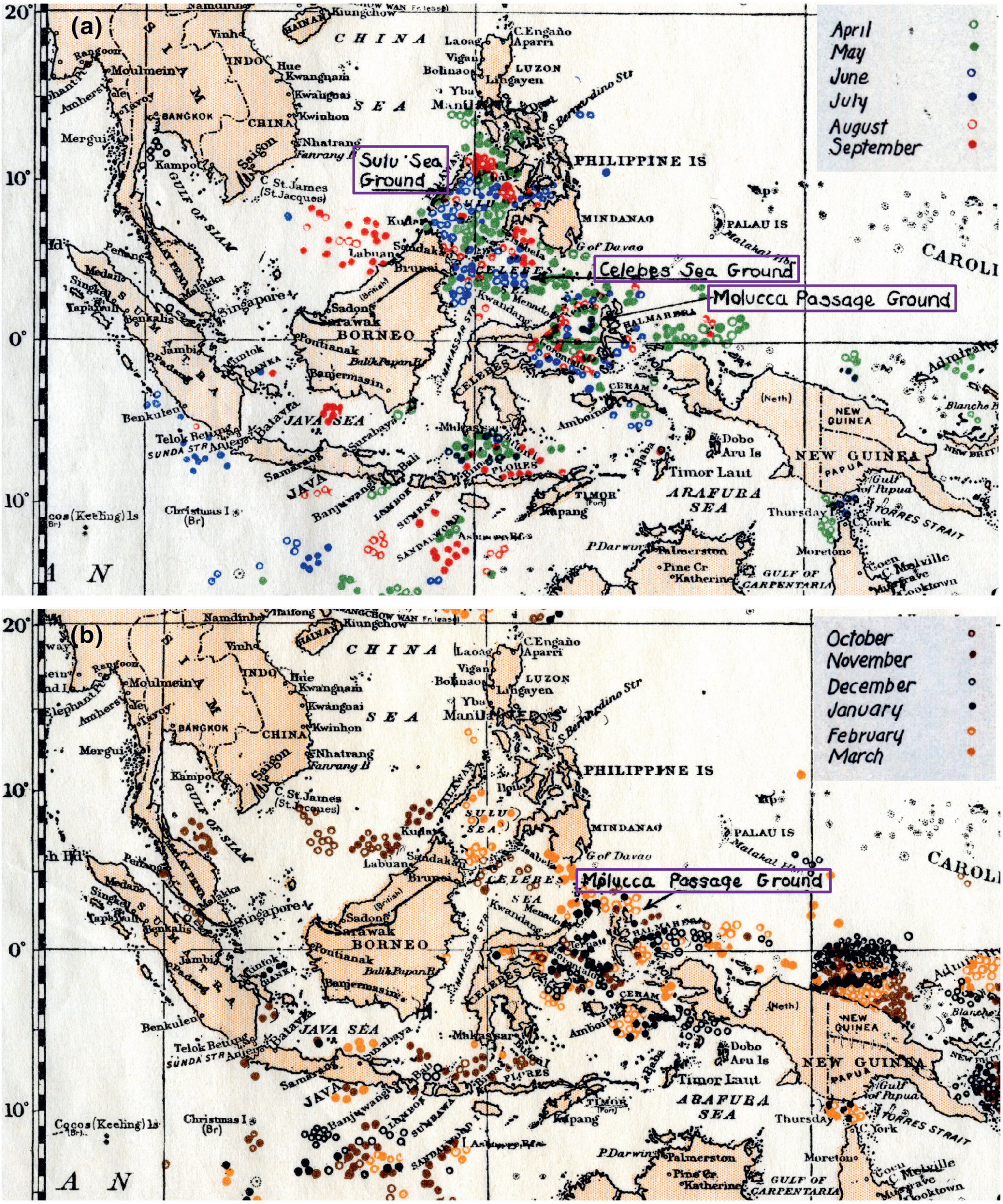


Fig. 3.1. Townsend's [78] sperm whale charts within Indonesian archipelago during Yankee whaling period 1761–1920: (a) April–September and (b) October–March. Reproduced with permission from the New Bedford Whaling Museum. The colours used to indicate the locations of sperm whale catches indicate the catch months. The whaling ground names are shown in purple boxes.

Species distribution models (SDMs) can provide quantitative predictions of the geographic distribution of species based on environmental variables. These results can then be used for conservation, policy and spatial planning. SDMs have been constructed based on historical whaling data before, and this has helped scientists to identify the core habitats of certain species, which is valuable for understanding species ecology and for conservation management [175,197,205,206] and provided improvements in the usability of the available data [14]. Identifying important habitats can help minimise adverse human and cetacean interactions [216] by implementing spatially explicit conservation measures. However, this attempt has never been done for Indonesian waters, even though it would provide important information about suitable sperm whale habitats.

The objective of this study was to identify important habitat areas for sperm whales within the Indonesian archipelago during the historical whaling era and to understand their past distribution patterns and seasonal differences. The relevance of the information gained from this study for current sperm whale management is also discussed.

3.2. Materials and Methods

3.2.1. Study area

The study area covers Indonesian waters from 92° to 143°E and from 9°N to 14°S (Fig. 3.2). The area spans c. 14.4 million km² and contains a diversity of habitat types, from shallow-sloping to deep-steep submerged waters (Supplementary Fig. A2a,b).

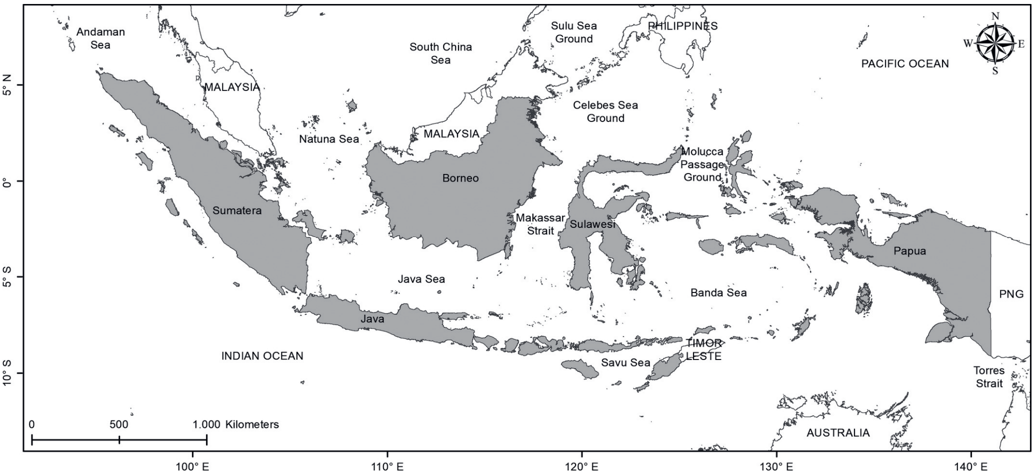


Fig. 3.2. Study area in the Indonesian archipelago. Names of seas and whaling grounds are used in the text.

3.2.2. Historical whaling data

The presence data of sperm whales (n = 793) were obtained from historical whaling (Townsend [78], Supplementary Fig. A2j). This information was available from sperm whalers' logbooks from the 18th to the early 20th century. Their voyages typically lasted 2–4 years, encompassing tropical and temperate seas throughout all seasons, only docking at port for supplies or repairs [78]. Age (juvenile, adult) and sex (male, female) segregation were not available from the dataset. However, as Yankee whaling focused on female social groups on tropical grounds [259,260], the sperm whales were assumed to be mainly adult females. We combined the whaling data into one all year dataset, ignoring seasons (hereafter, 'all year') and four independent groups based on the monsoonal seasons, i.e., Transition 1 (T1 season, March–May, n = 188), SE monsoon (June–August, n = 146), Transition 2 (T2 season, September–November, n = 207) and SW monsoon (December–February, n = 252).

The absence data were available from daily locations of vessels extracted from logbooks for voyages between 1780 and 1920 [202]. However, the amount of absence data was very limited and unevenly distributed over the study area (mostly in the southern part). As our preliminary work showed that this results in biased distribution models and poor model predictions (data not shown), we randomly generated 10,000 pseudo-absence data for the models as an alternative approach. It has been reported before that the ranks of habitat model calculated using presence and absence data were similar to that calculated using presence and pseudo-absence data [185].

3.2.3. Environmental variables

Twelve submerged topographic variables were selected based on the expected ecological relevance to sperm whale habitats [185,187,215,262,263] in the study area. Due to unavailability of data during the historical whaling period, and the uncertainty of their stability over time, dynamic oceanographic variables (e.g., chlorophyll-a concentration, sea surface temperature and sea surface salinity) were not included in this work. We checked the collinearity among variables and used only nine (Table 3.1) with Pearson's correlation values <0.75 (Supplementary Fig. A1) in modelling. These variables are bathymetry, slope as well as distance to- coast, −1,000 and −5,000 m isobaths, seamount, shelf, trench and trough (Supplementary Fig. A2).

Bathymetry data were obtained from the General Bathymetric Chart of the Ocean (GEBCO, https://www.gebco.net/), providing a 1-km grid of bathymetric surface for the study area. Slope was derived from the GEBCO using Spatial Analyst extension in ArcGIS 10.6.1 (Environmental Systems Research Institute, Inc.). Coastal lines were obtained from the Indonesian Geospatial Information Agency, while undersea topographic features were obtained from the Seafloor Geomorphic Features Map [264]. Distance to- coast, the two isobaths and topographic features were generated using the Euclidean Distance Tool-Spatial Analyst extension in ArcGIS 10.6.1. All variables were in ASCII raster format. The selection of spatial resolutions for environmental variables was primarily based on data availability. As bathymetry and slope were already in a 1×1 km^2 grid, the other variables were aggregated to match the same grid size and cover the same area. In total, there are 13,659,947 grids within the study area.

3.2.4. Species distribution modelling

We used two SDMs in this study: the maximum entropy model (Maxent) and the generalised additive model (GAM). The use of different models makes it possible to compare and evaluate their abilities and outputs, and thereby determine which models (and variables) describe the species distribution and habitat preferences with the greatest confidence.

Table 3.1. Environmental variables used for species distribution modelling

Variables	Unit	Sources	Rationale
Bathymetry	m	General Bathymetric Chart of the Ocean (GEBCO; https://www.gebco.net/)	Shallow water is associated with high primary production. Top predators respond to bathymetric features; shallow topography may provide favourable foraging opportunities [265]
Slope	%	(GEBCO; https://www.gebco.net/) and ArcGIS derived	Associated with currents, steep benthic relief promotes water movements. High slope induces prey aggregation and/or increases primary production [265]
Distance to isobaths:			
-200 m[a]	km	(GEBCO; https://www.gebco.net/) and ArcGIS derived	These distinct depths are associated with the deep diving habits of species [187,266]
-1000 m (d_1000)	km		
-2500 m[a]	km		
-5000 m (d_5000)	km		
Distance to:			
Coast (d_coast)	km	Indonesian Geospatial Information Agency and ArcGIS derived	Distance provides an indication of preference for near or offshore habitats [267]
Ridges [a]	km	Seafloor Geomorphic Features Map [264] and ArcGIS derived	Submerged geomorphic features increase the complexity of seafloor that is associated with currents. High topographic complexity can locally increase productivity, induce prey aggregation and provide migration cues [268]
Seamount (d_seamount)	km		
Shelf (d_shelf)	km		
Trench (d_trench)	km		
Trough (d_trough)	km		

[a] Variables that were eliminated due to multicollinearity. The variable names in parentheses in the first column are as named in our models and in Table 3.3.

Maxent is a presence-only model previously applied for cetacean distribution studies [186,269,270]. Maxent is advantageous for this study because it accounts for spatial bias in presence data and can identify areas that fall beyond the range of occupied environmental condition [166]. Maxent predicts a focal species' most uniform distribution across the study area (the distribution with maximum entropy), in relation to the environmental conditions at the locations of the presence data. The model is then extrapolated to other unsampled areas within the study area to give the habitat suitability of the species based on environmental characteristics of the sites

[166,271]. We used the Maximum Entropy Species Distribution Modelling software v. 3.4.1 (https://biodiversityinformatics.amnh.org/open_source/maxent).

The use of GAM is common in SDM because it allows the data to identify nonlinearity in species–habitat relationships rather than imposing parametric fits through polynomial terms in a linear regression [168,176]. GAM is a presence–absence model that has been applied for cetacean studies [191,215]. The GAM model attempts to differentiate the environmental conditions where the species is observed (presence points) and where it is absent (i.e., in pseudo-absence points). The preferred niche of the species was then projected onto the geographic space with its characteristics to depict its potential distribution. We used R package 'biomod2' v. 3.3-7.1 (https://cran.r-project.org/web/packages/biomod2/index.html).

To be able to make a comparison, the same settings were applied within both models: 30% random test percentage, 10 replicates with bootstrap replicated run type, regularization multiplier 1 and maximum number of randomly selected background points 10,000 (the last two parameters were set as defaults, see [166,175]). Both SDMs were built for each of the 'all year' and four monsoonal seasons (T1 season, SE monsoon, T2 season and SW monsoon). Maxent generates logistical spatial predictions of distribution with values between 0 (not suitable) and 1 (highly suitable), while that of GAM using Biomod2 ranges from 0 (not suitable) to 1,000 (highly suitable); therefore, the output values were standardised to be comparable. The correlation between the suitability values predicted by Maxent and GAM per cell values was calculated as a Pearson's correlation coefficient.

To distinguish suitable and unsuitable habitats, we applied the '10th percentile training presence threshold' to the predicted distribution maps (raster format) in ArcGIS 10.6.1. This threshold was chosen because it is the best threshold when true absence data are not available [272], and it selects values above which 90% of the training presence are correctly classified, thus giving conservative estimates of prediction [273]. The mean threshold of 10 replicates of each seasonal model was used as a binary threshold for presence/absence of sperm whales, above which a suitable habitat is considered to occur. To reveal seasonal similarities and differences in habitat suitability, a seasonal overlap map was generated with the best performing SDM (either Maxent or GAM, see below). The map was created by combining (stacking) the individual binary seasonal maps.

3.2.5. Model performance assessment

Species distribution models are commonly assessed by the Area Under the receiver-operating-characteristics (ROC) Curve, or AUC [166]. An AUC curve is a graphical plot which illustrates the probability that a random presence data point will be ranked above a random absence (or pseudo-absence) one [274]. The ROC curve shows 'sensitivity' over '1 minus specificity' at a range of threshold probability values, where the sensitivity is the proportion of observed presences correctly predicted by the model and the specificity is the proportion of observed absences (or pseudo-absences) correctly predicted by the model [275]. An AUC value above 0.5 indicates that the model performs better than random [178,271]. A potentially useful model will have an AUC above 0.75 [276].

We also applied two additional model evaluation metrics called True Skill Statistic or TSS [277] and Sensitivity. A TSS above 0.4 reflects a potentially useful model and above 0.6 is considered to denote good to excellent performance [278,279]. A model with a sensitivity value above 0.7 is considered a good model [280]. We used several evaluation metrics of model performances, because none are perfect when true absence data are not available. Significant differences for AUC, TSS and Sensitivity values between Maxent and GAM in 'all year' and each seasonal model were tested using a t-test.

The Jackknife test was used to determine the contribution of each environmental variable to the predicted output, by running the model with and without that variable. The percentage contribution to model gain and the permutation importance of each environmental variable used to build the model could then be assessed [166]. The environmental variables with the highest training gain are considered to have the highest contribution to the model.

3.3. Results

3.3.1. Historical distribution of sperm whale

The overall predictions per season are visually similar for both models (Fig. 3.3), and align closely with the whaling data. The patchiness of sperm whale distribution is evident in GAM, while the distributions modelled with Maxent were more continuous. Some obvious examples of the patchiness in GAM and the continuity in Maxent can be seen in the northern part of Papua island, and the south-western part of the Sumatera (Fig. 3.3).

The similarity of the spatial distributions between both models is also apparent from the high Pearson's correlation coefficients [215] between predicted grid values for sperm whale habitat suitability. The Pearson's correlations were high in all models, ranging from 0.705 to 0.851 (Fig. 3.3).

3.3.2. Performance of the models

The performance metrics, AUC, TSS and Sensitivity for Maxent and GAM are given in Table 3.2. Most model outputs predicted by both Maxent and GAM yielded good discrimination power, with AUC and Sensitivity values >0.75 and TSS values >0.4 indicating model robustness (Table 3.2). Maxent performed better than GAM, indicated by significantly higher AUC values for all modelled seasons. Sensitivity values of three Maxent outputs also were significantly higher than those of GAM.

However, based on TSS values, four of five model outputs did not significantly differ between Maxent and GAM. GAM never performed significantly better than Maxent (Table 3.2).

As can be seen in Fig. 3.3, the Maxent and GAM distributions fit the sperm whale catch data well. Both models predicted a high suitability of sperm whale habitat in several areas where catches were not reported. Some prominent examples were in the East Banda Sea during the SE monsoon, and in the West Banda Sea during the SW monsoon (Fig. 3.3).

Table 3.2. Performance metrics for Maxent and GAM

Season	Metric	Maxent	Sig [a]	GAM
All	AUC	0.806 ± 0.009	>	0.793 ± 0.011
	TSS	0.461 ± 0.023	ns	0.475 ± 0.020
	Sensitivity	0.888 ± 0.028	>	0.820 ± 0.041
T1	AUC	0.884 ± 0.010	>	0.815 ± 0.020
	TSS	0.575 ± 0.042	>	0.521 ± 0.041
	Sensitivity	0.825 ± 0.054	>	0.769 ± 0.071
SE	AUC	0.899 ± 0.014	>	0.810 ± 0.023
	TSS	0.511 ± 0.046	ns	0.514 ± 0.042
	Sensitivity	0.860 ± 0.045	>	0.802 ± 0.064
T2	AUC	0.874 ± 0.008	>	0.804 ± 0.013
	TSS	0.451 ± 0.036	ns	0.455 ± 0.029
	Sensitivity	0.810 ± 0.056	ns	0.798 ± 0.044
SW	AUC	0.895 ± 0.007	>	0.842 ± 0.020
	TSS	0.609 ± 0.048	ns	0.585 ± 0.035
	Sensitivity	0.839 ± 0.051	ns	0.846 ± 0.040

Abbreviations: All, all year; AUC, area under the curve; GAM, generalised additive model; SE, Southeast monsoon (June–August); SW, Southwest monsoon (December–February); T1, Transition 1 (March–May); T2, Transition 2 (September–November); TSS, True Skill Statistic.

[a] Significant differences in performance metrics (AUC, TSS, Sensitivity) between Maxent and GAM results were tested using t-test. '>' indicates Maxent performed significantly better than GAM, 'ns' indicates no significant difference. GAM never performed significantly better than Maxent.

3.3.3. Seasonal differences in distribution

The season-specific habitat suitability maps were generated with Maxent only because Maxent performed better than GAM (see Section 3.3.2). By regrouping the whale occurrences per quarter based on Indonesian monsoonal seasons, different seasonal positions of suitable habitat were revealed (Fig. 3.4).

A wide distribution of sperm whales was predicted in the South China Sea during the T2 season, which indicates possible seasonal migrations from surrounding Southeast Asian waters (Fig. 3.4). Limited or no sperm whale distribution was predicted in the Celebes Sea Ground during the SW monsoon, in the Indian Ocean south of Java island during the T1 season, in the Andaman Sea during the SE monsoon and in the Torres Strait during the T2 season (Fig. 3.4). A narrow distribution was also predicted to the north of Papua during the SE monsoon.

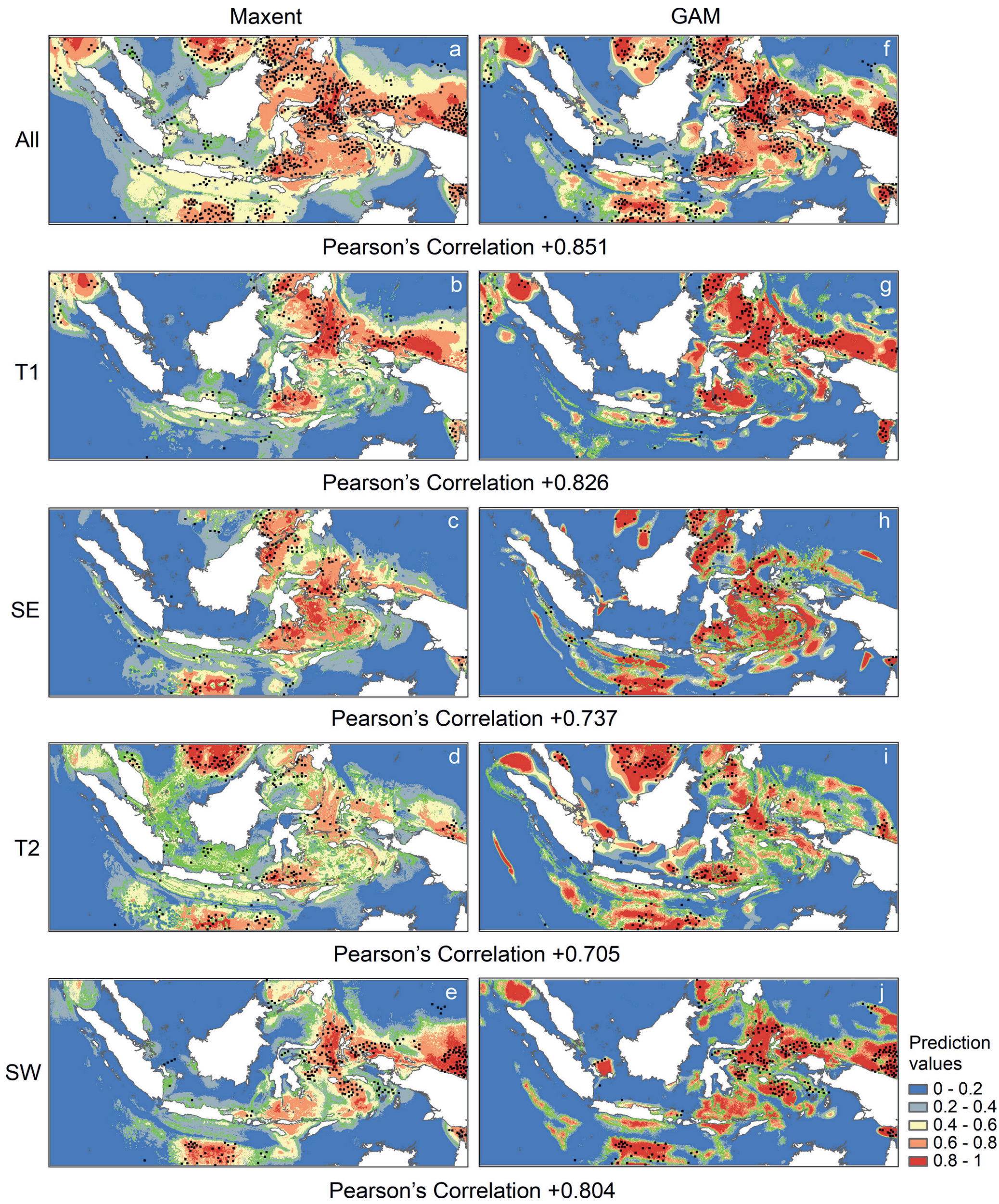


Fig. 3.3. Historical sperm whale distributions as predicted by Maxent and generalised additive model (GAM) for all year and per season: T1 = Transition 1 (March–May), SE = Southeast monsoon (June–August), T2 = Transition 2 (September–November), SW = Southwest monsoon (December–February). The prediction values range between 0 and 1 and are classified into five classes as shown in the bottom right corner, and the actual whale catch data are indicated by black squares (■). The Pearson's correlations between Maxent and GAM prediction values are given. Green lines indicate 10th percentile training presence threshold.

The seasonal overlap map (Fig. 3.4f) unveils some of the seasonal variability in sperm whale presence. In the four marked areas, no seasonal differences occur in sperm whale distribution, i.e., in the West Banda Sea, the Molucca Passage Ground, the North Papua and the Sulu Sea Ground, while noticeable seasonal differences in distribution were observed in other areas.

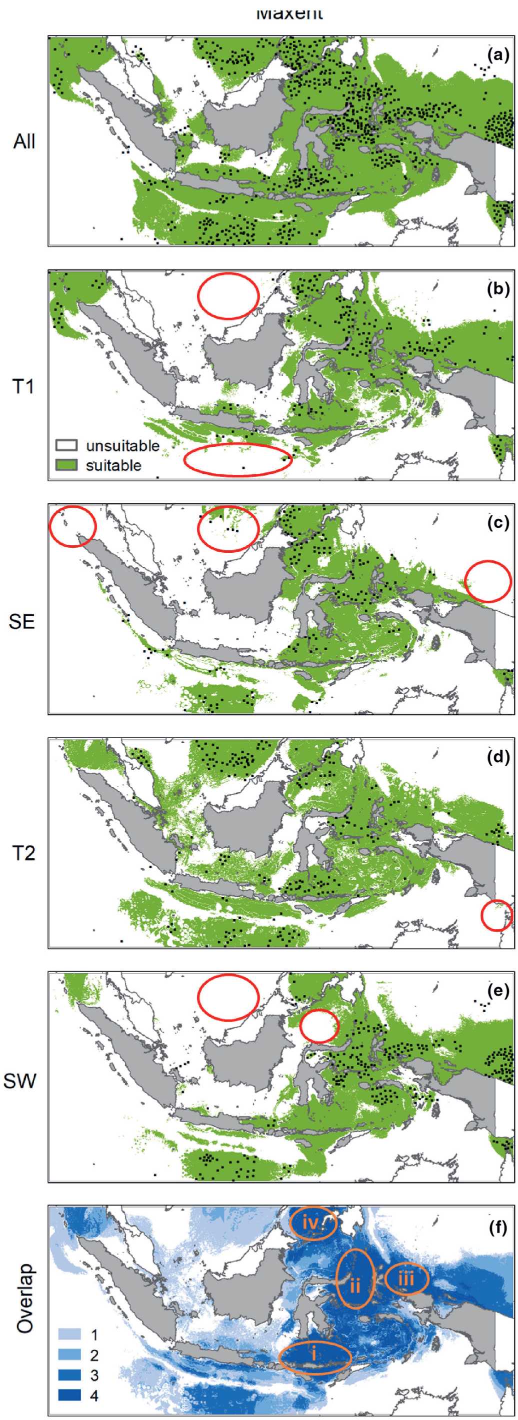


Fig. 3.4. Historical seasonal habitat suitability maps of sperm whale in Indonesia generated with the Maxent model (the first five figures). Suitable habitat is indicated in green and is season dependent: (a) All = all year (1761–1920), (b) T1 = Transition 1 (March–May), (c) SE = Southeast monsoon (June–August), (d) T2 = Transition 2 (September–November), (e) SW = Southwest monsoon (December–February). Red circles indicate the areas that differ most among seasons. The last figure (f) shows the degree of seasonal overlap of the distributions in increasingly dark blue colour, and the numbers 1–4 show the number of season(s) with overlapping distribution. Orange circles indicate areas without differences in distribution among seasons. (i) West Banda Sea, (ii) Molucca Passage Ground, (iii) Northern Papua, (iv) Sulu Sea Ground.

3.3.4. The importance of environmental variables for sperm whale distribution

Five of nine variables appeared to be important in defining environmental niches for the species. Only distance to coast was retained as the most important variable in all model outputs. The next variable most commonly retained was distance to trough (retained in 5 model outputs), followed by distance to- −1,000 and −5,000 m isobaths and trench (each in 4 model outputs). The remaining variables, except bathymetry and distance to seamount, were retained in only 1 or 2 model outputs (Table 3.3). In general, distance to- coast, −1,000 and −5,000 m isobaths, trough and trench were the most important variables that determined sperm whale habitat suitability (Table 3.3).

Table 3.3. Performance metrics for Maxent and GAM

Variables	Maxent					GAM				
	All	T1	SE	T2	SW	All	T1	SE	T2	SW
Bathymetry	0.081	0.042	0.076	0.093	0.106	0.021	0.098	0.067	0.037	0.017
d_1000	0.063	**0.127**	0.085	0.051	0.007	**0.164**	0.105	**0.188**	**0.187**	0.124
d_5000	0.075	0.052	0.073	0.087	**0.141**	**0.163**	**0.138**	0.101	**0.157**	0.124
d_coast	**0.390**	**0.354**	**0.214**	**0.202**	**0.251**	**0.324**	**0.268**	**0.177**	**0.190**	**0.252**
d_seamount	0.080	0.051	0.099	0.089	0.056	0.065	0.132	0.114	0.026	0.100
d_shelf	0.069	0.112	0.048	0.052	0.121	0.128	0.047	0.117	0.149	**0.154**
d_trench	0.049	0.100	0.079	**0.231**	**0.159**	0.069	**0.136**	0.098	0.111	**0.153**
d_trough	**0.091**	**0.119**	**0.197**	**0.143**	0.103	0.059	0.069	**0.120**	0.110	0.055
Slope	**0.103**	0.044	**0.129**	0.052	0.057	0.007	0.007	0.018	0.033	0.020

Note: Bold shaded numbers are the three most important variables that determine sperm whale habitat. The variable names in the first column are the names given in Table 3.1.
Abbreviations: All, all year; GAM, generalised additive model; SE, Southeast monsoon (June–August); SW, Southwest monsoon (December–February); T1, Transition 1 (March–May); T2, Transition 2 (September–November).

Three categories of variables determine sperm whale occurrence in habitat modelling (Fig. 3.5). First, variables that do significantly determine different whale distribution across seasons and available habitat. These variables were distance to- −5,000 m isobath, coast, trench and trough (Fig. 3.5f–i). Whales occurred mainly in areas with a distance of 118–151 km from the −5,000 m isobath in most seasons, but farther during the T2 season (median 176 km, the farthest is c. 700 km); closer to the coast (200 km) during the T1 season compared to available habitat (up to 375 km); closer to a trench during the SW monsoon and closer to a trough during the SE monsoon and the T2 seasons.

Second, variables that show the same between all four seasons: distance to −1,000 m isobath, distance to seamount and slope (Fig. 3.5c–e). Sperm whales mostly occurred close to the −1,000 m isobath (44–54 km), close to seamount (115–155 km compared with 180 km of available habitat) and were prevalent in areas with steeper slope (2.5%–3.2% compared to only 1.7% of available habitat).

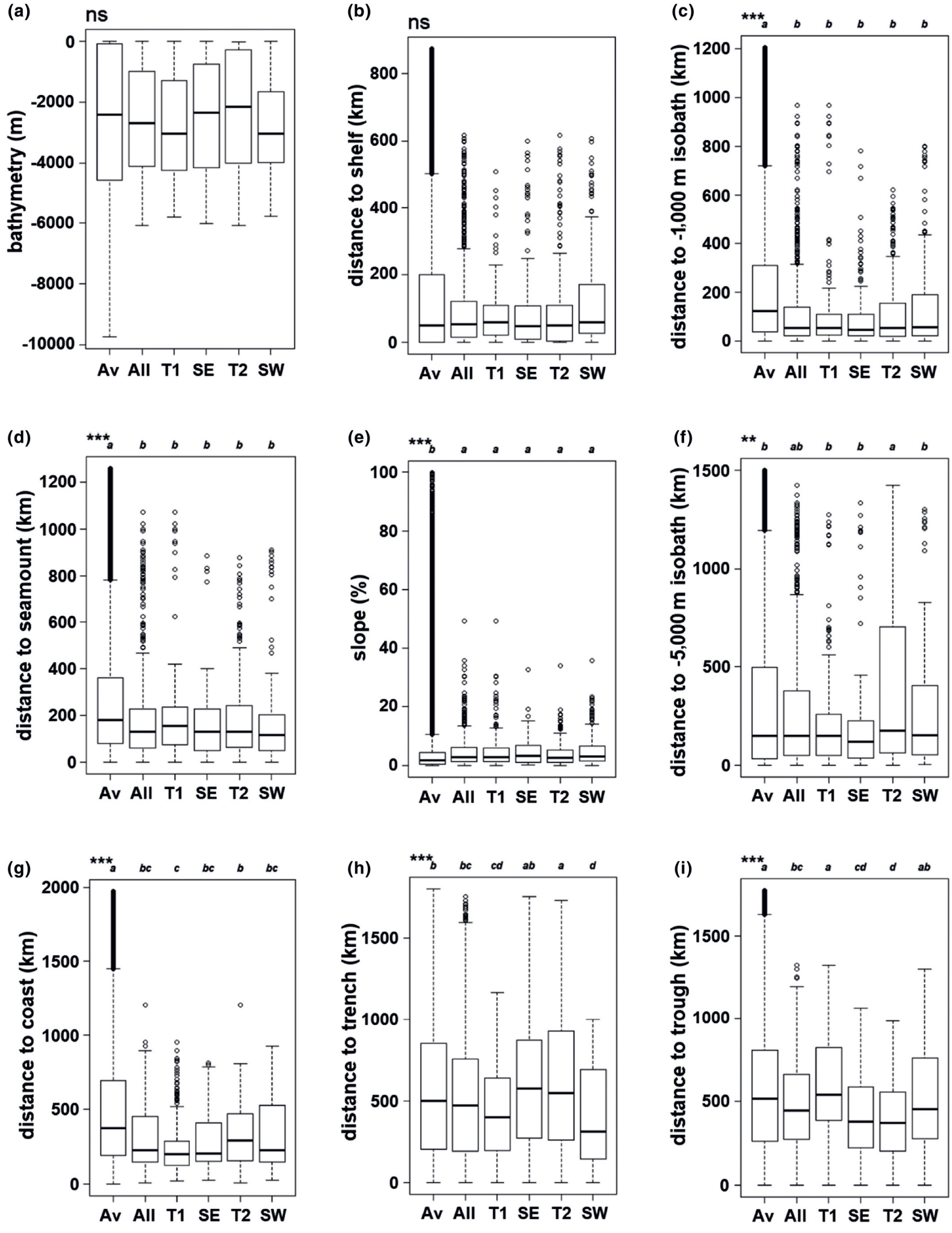


Fig. 3.5. Boxplots showing the habitat ranges of sperm whale clustered based on the variables used in the habitat modelling: (a) bathymetry (m); (b) distance to shelf (km); (c) distance to −1,000 m isobath (km); (d) distance to seamount (km); (e) slope (%); (f) distance to −5,000 m isobaths (km); (g) distance to coast (km); (h) distance to trench (km); (i) distance to trough (km). Av = value of a variable in available habitat (whole study area). All = All year, T1 = Transition 1 (March–May), SE = Southeast monsoon (June–August), T2 = Transition 2 (September–November), SW = Southwest monsoon (December–February). Significant differences among seasonal habitat ranges were checked using Kruskal–Wallis (**p <0.01, ***p <0.001, ns = not significant). Wilcoxon post hoc test was applied for multiple comparisons after Kruskal–Wallis testing indicated a significant difference. The same letters indicate the boxplots do not differ significantly.

Third, variables that do not determine sperm whale distribution in any season: bathymetry and distance to shelf (Fig. 3.5a,b). Sperm whales occurred in areas with bathymetry values ranging from −2,151 to −3,047 m (the median in the available habitat is −2,422 m), and were located 48–60 km from shelf (the median in the available habitat is 49 km) effectively occupying the full range of available values for these two variables.

3.4. Discussion

This study presents the first historical seasonal distribution modelling of sperm whales in Indonesian waters in relation to their habitat preferences. First, we evaluated the model outputs and their performance and caveats. Both Maxent and GAM predict a similar area of sperm whale distribution; and both distributions agree well with the whaling data. This work resulted in three main findings: identifying historical sperm whale seasonal distribution patterns, finding the important variables characterizing sperm whale habitat preferences and confirming the application of SDM based on historical whaling data to support conservation management.

3.4.1. Performance and caveats of models

The model evaluation metrics indicate that, overall, Maxent and GAM predicted reasonably well the distribution of the sperm whales based on environmental characteristics for 'all year' and each season (Fig. 3.3). The majority of the models showed moderate to high discrimination power based on AUC, TSS and sensitivity values. The standard deviation of the average AUC, TSS and sensitivity values was mostly small (<0.05) for each season, either in Maxent or GAM (Table 3.2). This indicates consistent and reliable model outputs, and appropriate robustness [279]. For extended analysis of the model performance and caveats see Supplementary Texts A1.

3.4.2. Historical sperm whale seasonal distribution patterns

The modelled sperm whale distributions clearly show that important sperm whale habitats were located mainly in the eastern part of the equatorial Indonesian waters. Four areas were identified as important habitats for sperm whales in any season, while they were seasonally absent in other locations (Fig. 3.4). Several studies have reported historical year-round presence of sperm whales in the low-latitude areas [202,281] which is corroborated by our results. Townsend [78] reported sperm whale occurrences in the form of 'points', while this study provides a continuous surface distribution based on the SDMs. Because Townsend plotted the data in two-half-year periods (Fig. 3.1), it seems sperm whales occurred in the north of Borneo island year-round. However, our plotting and modelling based on Indonesian monsoonal seasons reveals they mainly occur there during the T2 season (inter-monsoonal season, September–November; Figs. 3.3d and 3.4d).

Migrations of the sperm whale are poorly understood compared to other large whales such as baleen whales. While male sperm whales are reported to move to higher latitudes in summer, females (as in our study) remain in equatorial and lower latitudes throughout the year [282] and their seasonal migration routes are unknown [260,282,283]. Availability of different types of prey is suggested to drive these sex-specific movement patterns [284]. In the Galapagos, a comparable equatorial area, upwelling events mainly driven by increasing sea surface temperature increased the feeding success of migrating sperm whales [284,285]. A study on historical trends of sperm whale stranding events in the North Sea suggested that they mainly occurred around migration events and were associated with increased temperature anomalies [286]. For our study area, during the T2 season the water temperatures at northern latitudes start to drop and the sperm whales were assumed to migrate from other parts of Southeast Asia to the north of Borneo. However, no sperm whales were found in this region during the SW monsoon coinciding with winter in northern latitudes. It therefore seems that sperm whales continue dispersing to other locations. Additionally, the monsoonal regime with seasonally reversing currents leading to water exchange [73] potentially drives the seasonal upwelling in these waters which enhances local productivity that may attract the whales. This should be corroborated by more targeted future research.

The consistent occurrence of sperm whales in certain areas during specific seasons (Fig. 3.4) suggests site fidelity of the species. This is in accordance with observations reported for other areas [287]. Site fidelity is characteristic of sperm whales [288] and has been supported by genetic studies [289]. Our modelling showed that the animals were permanently present in four core areas, the West Banda Sea, the Molucca Passage Ground, northern Papua and the Sulu Sea Ground, while modelled and observed sperm whale distribution varied greatly between seasons in other places. This habitat segregation over the seasons (Fig. 3.4) includes the high density of animals in the north of Borneo Island exclusively during the T2 season and the absence of sperm whales in the Andaman Sea during the SE monsoon and in the Torres Strait during the T2 season. Sperm whales have been known to exhibit seasonal changes in their distribution associated with migratory movements [202]. Of course, it is important to realise that historical whaling data not only reflect the presence of the animals but could also be influenced by seasonal differences in catch effort (see Ref. [260]) and differences in the amount of presence data from Townsend [78] by season.

The absence of sperm whales at several locations in the modelled distributions (Fig. 3.4, red circles) does not necessarily indicate unsuitable habitat; it could also be due to the absence of (successful) whaling at that location during that season. The same absence could occur nowadays through non-occupancy during times of observation effort [197]. As the animals may also follow prey abundance, additional local physical and biological processes that cause prey to aggregate [290] may account for part of the unexplained deviances of the sperm whale reports from the predicted distribution. Unfortunately, variables that directly quantify the productivity (e.g., chlorophyll-a concentrations and sea surface temperature) during the historical whaling period were not available. Exploring the potential use of current dynamic variables for historical sperm whale distribution modelling could be the focus of future research.

3.4.3. Important variables characterizing sperm whale habitat preferences

The habitat preferences of sperm whales over the seasons are also reflected in the set of important environmental variables for each modelled distribution. A key environmental factor in explaining sperm whale distribution for both Maxent and GAM in all seasons was distance to coast. More productive areas are closer to the coast [215], which the whales seem to take advantage of. The fact that commercial whaling activity in Western Australia also occurred primarily relatively close to land [187] corroborates our current study results that distance to coast considerably determines their habitat. Prey abundance has indeed been reported to be generally higher in coastal waters [14], possibly explaining the more suitable habitat closer to the coast, as highlighted for all seasons by both Maxent and GAM.

Distance to trough and trench were the next most important variables in predicting sperm whale distribution (Table 3.3). These variables reflect increased topographic complexity that may be important in creating physical processes that support enough productivity and associated cephalopods to attract sperm whales [268,283]. Prey availability, however, could not be included in the current study as data for this from the historical whaling era are sparsely available. Although oceanographic and biological variables such as sea surface temperature and chlorophyll-a concentration can serve as proxies of prey species density, the availability of such data is also very limited for this period. Unravelling the parameters that determine the species' ecological niche requires fine-scale seasonally dependent habitat use studies, investigating among other things prey distribution, associated cetacean foraging behaviour as well as predator avoidance strategies. Such ecological information can provide a more comprehensive selection of input variables to fine-tune the distribution models.

Distance to −1,000 and −5,000 m isobaths were the next most important variables, particularly for GAM model outputs (Table 3.3). During the historical and commercial whaling era, most whales were killed offshore in very deep waters with a median depth of c. −5,000 m [187]. The high presence in very deep waters shown in our habitat modelling aligns with the deep diving habits of the sperm whales to catch their primary food source, cephalopods [283]. In the study area, −5,000 m isobath (Supplementary Fig. A2d) also coincides with complex topographic features like seamounts (Supplementary Fig. A2f) and steep slope seabed (Supplementary Fig. A2b), although seamounts did not significantly influence our models. Distance to the −1,000 m isobath has also been indicated as suitable habitat for foraging sperm whales in other regions for other types of prey [291–294]. In Western Australia, sperm whales also occurred at this depth, as commercial whaling locations were reported to have a median depth of around −1,000 m [187]. Another toothed whale, the short-finned pilot whale, has also been reported to forage on mesopelagic cephalopods at a depth of c. −1,000 m [295].

Previous studies have indicated that slope is an environmental factor influencing sperm whale distribution [292,294], and sperm whales are more prevalent in areas with a steeper slope [296]. However, we only found a relationship between slope and the modelled whale distributions for the Maxent outputs in 'all year' and SE monsoon. Sperm whales often occur close to the shelf edge [283] due to the presence of upwelling-modified waters [185].

Both Maxent and GAM failed to identify bathymetry and seamount as important variables in predicting sperm whale distribution, therefore the two variables were not retained in the model outputs. Other studies, however, did find a relationship between bathymetry and presence of whales in general [292,294]. This is often the case for the distribution of whale species that feed on benthic prey following seafloor structures [297,298], instead of deep-diving pelagic species like sperm whale. Our results are also in agreement with Morato et al. [299] and Tobeña et al. [279] who found that current sperm whale sighting frequencies were not influenced by distance to seamount.

3.4.4. How SDM based on historical data can help conservation management

Our models provide spatial maps of the former distribution of sperm whales and their seasonal difference patterns for a vast area of the equatorial Indonesian marine ecosystem. Our predicted distributions can help to clarify the history of the exploitation of this species by exploring the surviving historical records in the light of these results. Understanding the past distribution of a species is important in order to recognise the past population structure [300], the migration paths [301] and the niches that are valuable to the species [302]. As the current populations of marine animals could capture a fraction of their historical occurrences [201], the historical distribution from our study can be used as a guideline to assess present species occurrence and eventually direct ecological investigation for future management support. For instance, marine protected areas and marine spatial planning in Indonesia should take into account species seasonal variability. The historical data may also demonstrate that areas now considered to be abundant in sperm whales only represent a fragment of former densities that used to occur there, as intensive exploitation in the past may have led to a shifting baseline in species densities [29]. It is not certain, however, whether or not contemporary sperm whale populations occupy the same habitats and seasonal migration paths as former populations. To understand this issue, further habitat modelling of modern sperm whale distribution using current data is needed.

The habitat preference assessment performed in this study can help determine suitable habitats for sperm whales in Indonesian waters, where little or no published data on its distribution exist, to inform future marine management and policy. The results of this study can be used to prioritise current sperm whale research and monitoring efforts in the areas predicted to be core sperm whale habitats: West Banda Sea, Molucca Passage Ground and Bird's Head Seascape-northern Papua in all seasons (Fig. 3.4). This is especially important as these habitats overlap with some of the busiest shipping routes in the world [303], and therefore may require mitigation measures. This will help us to gain a better understanding of the interactions between the animals and their environment, and how the population may respond to human disturbances and changes in their habitat. Our results also show that inter-island areas are very important for sperm whales and thus deserve special attention regarding the management of human activities that may threaten the cetaceans.

This study shows that sperm whales were very likely to be found year-round in equatorial Indonesian waters during the whaling era, with important habitats in the four aforementioned areas. In addition, our results show that sperm whale distribution varied substantially between seasons in other places. The use of historical whaling data in habitat models appears to be a promising approach to accelerate our knowledge on equatorial marine mammal distribution. Although the historical whaling data were not collected in a scientifically systematic way, it still provides important information in a cost-effective manner for a region for which knowledge is sparse. The habitat models synthesised which environmental factors are the primary determinants of habitat suitability for sperm whales from the historical whaling data. Incorporating such an unconventional dataset into habitat models yields benefits for scientific understanding of sperm whale habitat preferences as well as former sperm whale occurrences. This information can support management decisions on conservation measures for endangered large whales such as sperm whales.

Conflict of interest

The authors declare no conflict of interest regarding the results presented in this study.

Acknowledgements

This work was financially supported by the Indonesia Endowment Fund for Education (LPDP) Scholarship from the Ministry of Finance of the Republic of Indonesia for the first author (contract number: PRJ-482/LPDP.3/2017). The authors would like to thank Neftalí Sillero for his valuable input on habitat modelling, and the New Bedford Whaling Museum for permitting the historical whaling data and maps to be used in this study.

Data availability statement

The original data for this study are available from Townsend [78] with the permission from the New Bedford Whaling Museum. The processed data in raster format are available at Dryad (https://doi.org/10.5061/dryad.18931zct6).

Supplementary information

Supplementary materials of this article can be downloaded at https://onlinelibrary.wiley.com/action/downloadSupplement?doi=10.1111%2Fjbi.13931&file=jbi13931-sup-0001-Supinfo.docx.

“All models are simplifications of real systems.”

Randall J. Hunt

Chapter 4

Cetacean habitat modelling to inform conservation management, marine spatial planning, and as a basis for anthropogenic threat mitigation in Indonesia

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Published as: A. Sahri, M.I.H. Putra, P.L.K. Mustika, D. Kreb, A.J. Murk. (2021). Cetacean habitat modelling to inform conservation management, marine spatial planning, and as a basis for anthropogenic threat mitigation in Indonesia. Ocean & Coastal Management, 205: 105555. https://doi.org/10.1016/j.ocecoaman.2021.105555

Abstract
Indonesia harbours a high diversity of cetaceans, yet effective conservation is hampered by a lack of knowledge about cetacean spatial distribution and habitat preferences. This study aimed to address this knowledge gap at an adequate resolution to support national cetacean conservation and management planning. Maximum Entropy (Maxent) modelling was used to map the distribution of 15 selected cetacean species in seven areas within Indonesian waters using recent cetacean presence datasets as well as environmental predictors (topographic and oceanographic variables). We then combined the individual species suitable habitat maps and overlaid them with provincial marine spatial planning (MSP) jurisdictions, marine protected areas (MPAs), oil and gas contract areas, and marine traffic density. Our results reflect a great heterogeneity in distribution among species and within species among different locations. This heterogeneity reflects an interrelated influence of topographic variables and oceanographic processes on the distribution of cetacean species. Bathymetry, distance to- coast and the −200m isobaths, chlorophyll-a concentration (Chl-a) and sea surface temperature (SST) were important variables influencing distribution of most species in many regions. Areas rich in species were mainly related to coastal areas or insular-reef complexity, representing high productivity and upwelling-modified waters. Although some important suitable habitats currently fall within MPAs, other areas are not and overlap with oil and gas exploration activities and marine traffic, indicating potentially high risk areas for cetaceans. The results of this study can support national cetacean conservation and management planning, and be used to reduce or avoid adverse anthropogenic threats. We advise to consider currently unprotected suitable cetacean habitats in MPA and MSP development.

Keywords: cetacean, marine protected area, marine spatial planning, marine traffic, Maxent, oil and gas, species distribution model

4.1. Introduction

Biodiversity conservation and area-based management call for adequate-resolution species distribution data. Understanding the spatial distribution and habitat preferences of marine mammal species is a high priority for effective conservation management. A principal phase underpinning marine spatial planning (MSP) involves mapping the spatial distribution of ecological processes and biological features [96,97]. Protecting important habitats of top marine species is also a priority issue for MSP development [98]. However, often this information is lacking, inhibiting conservation efforts of these marine species. A sound management plan which adopts the most effective measures to protect marine mammals is clearly constrained by the knowledge on the species' critical habitats.

Cetaceans are well-known as charismatic species, and as top predators they could have strong effects on community structure and function [9]. The management of protected areas designed for top predators as umbrella species is highly efficient, resulting in higher biodiversity and more ecosystem benefits [8]. However, there is a long history of anthropogenic impacts on cetaceans through whaling, habitat degradation and increased activities in the marine environment that could adversely affect cetaceans [36]. Cetaceans are particularly susceptible to human threats because of their life-history traits, i.e., late maturity and low reproductive rate [58]. The variety of anthropogenic pressures includes interactions with fisheries (entanglement, bycatch, prey depletion) [38,39], physical and acoustic disturbance mainly by marine traffic (ship strikes, underwater noise) [43,44], seismic activities from oil and gas exploration and naval sonars [46,47], and pollution (oil spills, plastic debris, heavy metals, and other chemicals) [34,48–50]. New threats have also been recognised, including coastal-offshore development and energy production, resource extraction, tourism, and climate change [57,58]. A prominent stressor to cetaceans is shipping traffic [304]. Large whales are vulnerable to collisions with vessels throughout the world's oceans [45]. In addition, marine activity due to oil and gas exploration and extraction is also growing [163] and this has a major impact on marine life and environment [262], mainly from noise and potential pollutants. Understanding how both marine traffic and oil-gas related activities overlay with marine mammals' distributions is crucial for improving future decision-making regarding the zoning of multiple-use MPAs and MSPs.

The Indonesian archipelago holds a high diversity of cetacean species with 34 cetacean species recorded so far [53], accounting for more than a third of cetacean species worldwide [22]. The archipelago was previously one of the largest global whaling grounds [77,78] and is highly biologically productive. Indonesia is situated in an upwelling system, where wind regimes and oceanic currents strongly influence the temperature and primary productivity [73,74], benefiting marine species at all levels of the food web, including cetaceans [72]. Knowledge on cetacean distribution in

Indonesia, however, is not homogeneous, spatially or temporally. There have been relatively few recent cetacean surveys in Indonesia due to its vast area, remote offshore locations, poor weather and sea conditions, limited financial resources for research, and other logistic constraints [126]. Several locations have received survey coverage, mainly in the Lesser Sunda (including Bali and Solor-Alor), Papua, East Kalimantan, West Sumatra and Banda Sea [55,195,305–307]. These surveys were often undertaken in the framework of wildlife conservation through the establishment of MPAs. No studies have yet assessed the distribution of cetaceans in the whole Indonesian archipelago.

All marine mammal species in Indonesia are under strict protection according to the national regulation [308], where all species are listed in the annex of the Government Regulation No. 7/1999 [309]. Based on the online database of the International Union for Conservation of Nature [229], the status of more than a fifth of the cetacean species that occur in Indonesian waters is listed as 'threatened'. Information about the spatial distribution of these species is even still very limited, yet determining areas that require protection at appropriate scales for national management requires a finer understanding of the species habitat [13,310]. Typically, however, such information is only available in broad geographic regions and usually only in a coarse resolution and for a limited number of species [311,312]. In Indonesia, no distribution maps are available at eco-regional or seascape scales. The need for mapping critical habitat for cetaceans in Indonesia was indicated by the National Plan of Action (NPOA) for Cetaceans [53] and under the Regional Plan of Action (RPOA) for the Coral Triangle Initiative [80] as well as national legislation [82]. They ask for a better understanding of the biology and ecology of cetaceans for conservation purposes. Knowledge on distribution and habitat preference would enable stakeholders to minimise harmful human and cetacean interactions and implement spatially explicit conservation measures in a certain region. Combining cetacean habitat maps and maps of human activities to identify areas of high impact has not been attempted for Indonesia before.

Species distribution models (SDMs) are increasingly used in conservation planning and wildlife management, including for cetaceans [155], especially in developing MSP and designing MPAs [158] and identifying areas of potential conflict between human activities and marine organisms [159]. The models can provide a finer spatial resolution than traditional abundance estimates [151]. One of the powerful modelling tools used by numerous studies for cetacean species worldwide is Maximum Entropy (Maxent) [216]. As a presence-only technique, Maxent is particularly useful for studies of species with large ranges and small sample sizes, for regions where systematic surveys are sparse and/or limited in coverage, and for datasets for which absence or effort data are not available [175,258]. Using this modelling technique, it is possible to predict suitable habitats for a range of species and ultimately map areas of high cetacean diversity that is particularly useful for managers and decision-makers [151].

This study aims to provide adequate-resolution maps of cetacean distribution and habitat suitability in Indonesia and assess areal overlaps with MPAs, MSPs, and two anthropogenic threats, i.e., oil and gas concessions and marine traffic. The information from this study is crucial and particularly needed by the Indonesian government to be able to manage their national scale habitats to ensure species' protection as well as to guide policies mitigating anthropogenic threats.

4.2. Materials and Methods

4.2.1. Study area

In this study, seven regions within Indonesian waters are included: Sunda Strait (SS), Balikpapan Bay (BB), NE Borneo Seascape (NEBS), SE Sulawesi Seascape (SESS), Lesser Sunda Ecoregion (LSE), Bird's Head Seascape (BHS), and Fakfak Seascape (FS) (Fig. 4.1). These regions are chosen based on the availability of sufficient sighting data. The boundaries of the regions used either ecoregions or seascapes depend on the geographical distribution and the extent of presence data, with the exception of the two first regions that were determined based on the MSP jurisdiction (~12 nm from coastlines). Ecoregions or seascapes were chosen, since the boundaries are scientifically-determined and ecologically based [69].

4.2.2. Sighting data

Species presence data were collected from multiple sources from several cetacean programs in Indonesia from 2000 to 2018 (Fig. 4.1). These are currently the best sources of information on the occurrence of cetaceans in the Indonesian archipelago. The list of species, the number of sightings, and the number of sightings used in SDMs, however, were different in each region (Supplementary Table S1). The data were collected from both dedicated surveys (only in Balikpapan Bay) and non-systematic surveys from a range of platforms of opportunity (e.g. from fishing monitoring boats and hydro-oceanography survey boats) during several years. In order to improve the number of sightings, records from several surveys were pooled, regardless of the survey methods. Long term and pooled data capture both inter-seasonal and inter-annual variability in cetacean distribution [217]. Only species with ≥10 sightings in a region were included in SDMs, as this is the minimum number of sightings for which the tested models in previous studies reached the constant higher accuracy level i.e. the asymptotic point where the accuracy curve plateaued [313,314], meaning that the models were performed well with minimum 10 sighting data points. This treatment resulted in 15 species out of 34 being used for this study (Supplementary Table S1). The other 19 species were not included in our study, because of insufficient sighting data.

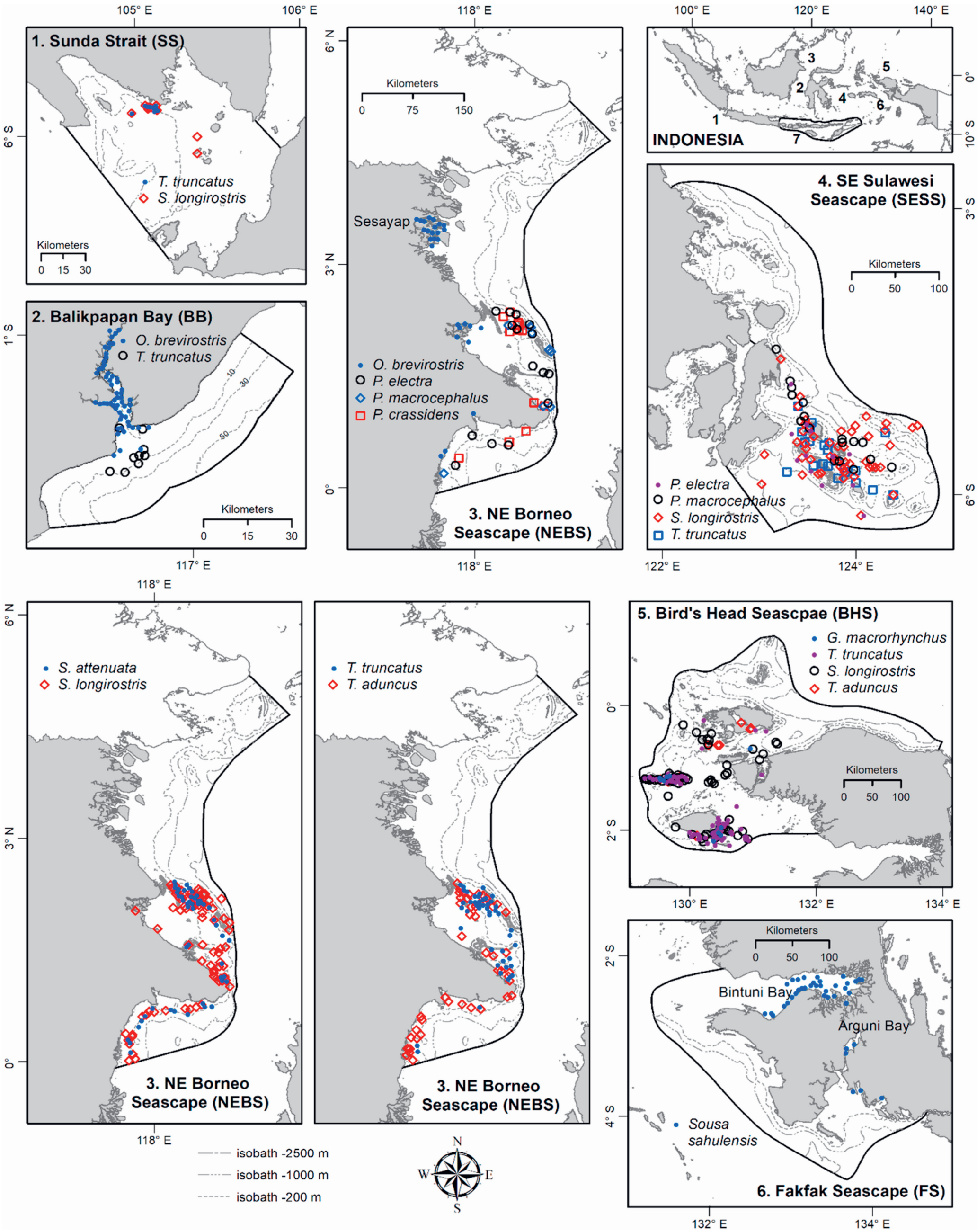

Fig. 4.1. Seven regions in Indonesia (#7 on the next page) that were included in this study with the reported presences of the 15 selected cetacean species (in total n=1276) used in Maxent. The isobaths (-200, -1000, and -2500m) are indicated (see below the maps of region 3), and only region 2 (Balikpapan Bay) has different isobaths (-10, -30, and -50m).

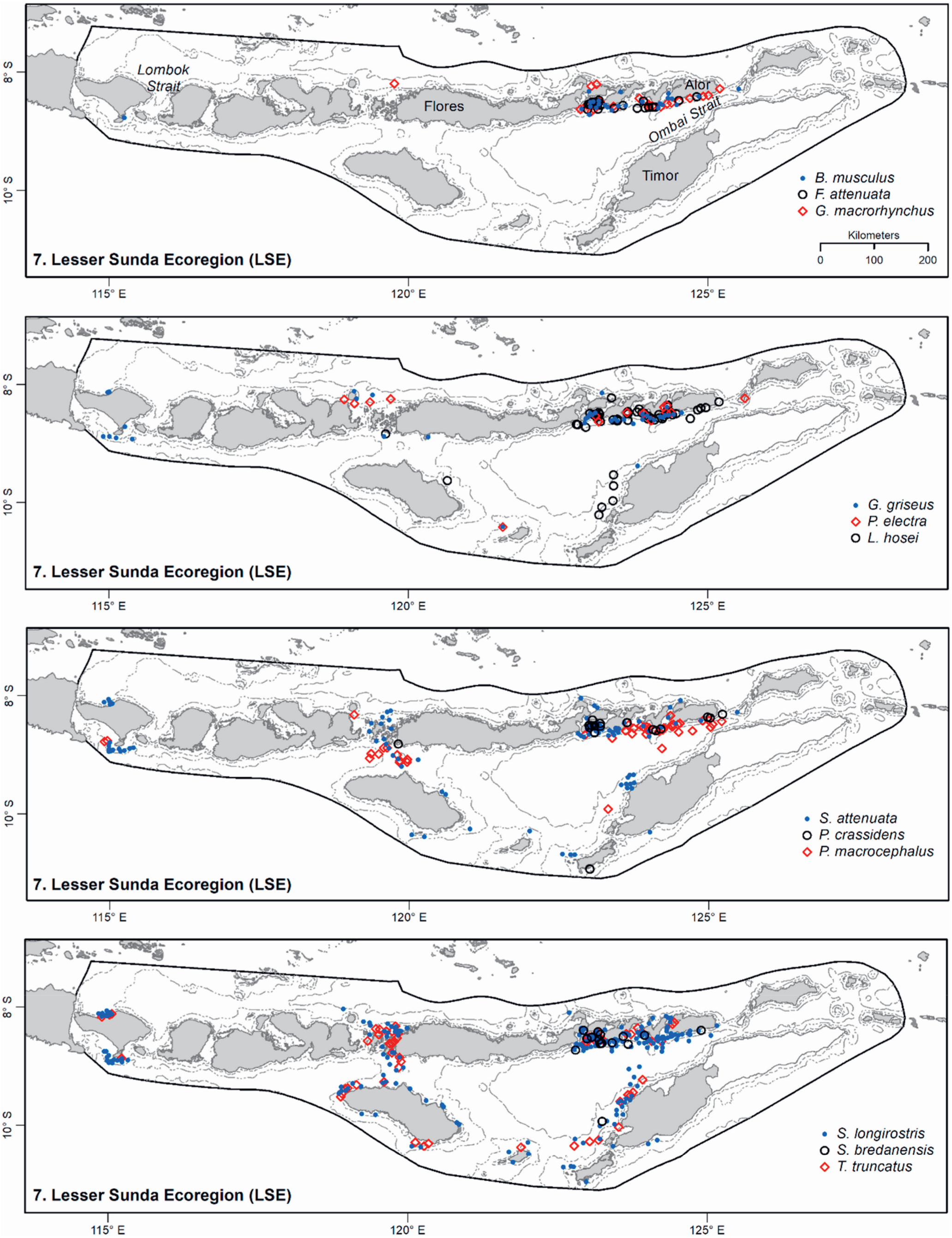

Fig. 4.1 (*continued*). Seven regions in Indonesia (#1-6 on previous page) that were included in this study with the reported presences of the 15 selected cetacean species (in total n=1276) used in Maxent. The isobaths (-200, -1000, and -2500m) are indicated (see below the maps of region 3), and only region 2 (Balikpapan Bay) has different isobaths (-10, -30, and -50m).

To avoid model over-fit, occurrence data should be spatially independent (free from spatial autocorrelation). An over-fitted model will reduce the model's ability to predict spatially independent data and inflate model performance values [315]. The 'Spatially rarefy occurrence data tool' in SDMtoolbox 2.0 [316] was used to spatially filter locality data by a pre-determined distance, reducing occurrence localities to a single point within the specified Euclidean distance or according to spatial heterogeneity of environmental variables. The maximum distance of 3 km (1 km for two smaller regions: the SS and BB) was used for sighting rarefying because of the high spatial heterogeneity in this study area and to prevent loss of many occurrence data. This graduated filtering method is particularly useful for this study, since most sighting records were concentrated in certain locations as consequence of non-systematic surveys, so they might be spatially correlated. After the rarefying process, a total of 1276 presence-only data points of the original 2252 data points for 15 cetacean species were used in Maxent.

4.2.3. Environmental predictors

Ten variables were selected in the study area (Table 4.1) that can be categorised into two types i.e., topographic variables (bathymetry, slope, distance to-coast, shelf, −200m, −1000m, and −2500m isobaths), and oceanographic variables (sea surface temperature (SST), sea surface salinity (SSS), chlorophyll-a concentration (Chl-a)). These environmental features have been used to understand cetacean habitat in many studies [10,215,262,317]. The collinearity among variables was checked in each region and only variables with Pearson's correlation values less than 0.75 were included in ecological modelling. The 'Remove highly correlated variables tool' in SDMtoolbox 2.0 [316] was used to check the collinearity among variables and eliminate correlated variables. Therefore, the selected variables used in modelling were different in each region (Table 4.2).

Bathymetry data with a 1 km^2 grid were obtained from the General Bathymetric Chart of the Oceans (GEBCO, https://www.gebco.net). Slope was derived from the GEBCO using the 'Spatial Analyst extension' in ArcGIS 10.3 (Environmental Systems Research Institute, Inc.). The coastlines were obtained from the Indonesian Geospatial Information Agency, while submarine shelf was acquired from the Seafloor Geomorphic Features Map [264]. Isobaths of −200m, −1000m, and −2500m were generated from the bathymetry data using the 'Contour tool-Spatial Analyst extension' in ArcGIS 10.3. Distance to- coast, shelf, and the three isobaths were generated using the 'Euclidean Distance tool-Spatial Analyst extension' in ArcGIS 10.3. The SST and Chl-a data were downloaded from Aqua MODIS (https://oceancolor.gsfc.nasa.gov), while the SSS data were downloaded from SODA 3.3.1 (http://apdrc.soest.hawaii.edu). Mean annual SST, Chl-a, and SSS from daily records covering the same time frame as the sightings data were used. The 'Inverse distance weighted (IDW) algorithm' in ArcGIS 10.3 was used to interpolate the spatial data of these oceanographic variables. The selection of spatial resolutions for final environmental variables was primarily based on data availability. Since bathymetry and slope were already in a 1 km^2 grid, the other variables were aggregated to match the same grid size and cover the same area in each region.

Table 4.1. Environmental predictors available for the study areas and the information sources

Predictors	Unit	Source
Bathymetry	m	GEBCO (https://www.gebco.net)
Slope	%	GEBCO and ArcGIS derived
Distance to isobaths:		
-200 m (d_200)	km	GEBCO and ArcGIS derived
-1000 m (d_1000)	km	GEBCO and ArcGIS derived
-2500 m (d_2500)	km	GEBCO and ArcGIS derived
Distance to:		
coast (d_coast)	km	Indonesian Geospatial Information Agency; ArcGIS derived
shelf (d_shelf)	km	Seafloor Geomorphic Features Map [264]; ArcGIS derived
Oceanographic predictors:		
Sea surface temperature (SST)	°C	Aqua MODIS (https://oceancolor.gsfc.nasa.gov)
Sea surface salinity (SSS)	PSU	SODA 3.3.1 (http://apdrc.soest.hawaii.edu)
Chlorophyll-a (Chl-a)	mg.m^{-3}	Aqua MODIS (https://oceancolor.gsfc.nasa.gov)

Table 4.2. Environmental predictors used per area in the Maxent models (unless removed based on multi-collinearity test, indicated with '*')

Predictors	SS	BB	NEBS	SESS	LSE	BHS	FS
Bathymetry	v	v	v	v	v	v	v
Slope	v	v	v	v	v	v	v
Distance to isobaths:							
-200 m (d_200)	v	n.a	v	v	v	v	*
-1000 m (d_1000)	v	n.a	v	v	v	n.a	n.a
-2500 m (d_2500)	n.a	n.a	*	v	v	v	n.a
Distance to:							
coast (d_coast)	v	n.a	v	*	*	v	v
shelf (d_shelf)	*	n.a	*	*	*	*	*
Oceanographic predictors:							
Sea surface temperature (SST)	v	v	*	v	v	v	v
Sea surface salinity (SSS)	*	v	v	v	v	*	v
Chlorophyll-a (Chl-a)	v	*	v	v	v	v	*

n.a : predictor was not available for the specific region, so was not used in the modelling
'v' indicates the variables that were used in the models in each region
SS: Sunda Strait, BB: Balikpapan Bay, NEBS: NE Borneo Seascape, SESS: SE Sulawesi Seascape, LSE: Lesser Sunda Ecoregion, BHS: Bird's Head Seascape, FS: Fakfak Seascape.

4.2.4. Maxent model setting

Maxent software version 3.4.1 (https://biodiversityinformatics.amnh.org/open_source/maxent) was used to generate probabilistic predictions and habitat models for each cetacean species. This software is a maximum entropy algorithm, specifically developed for presence-only data [166]. Maxent has been successfully applied in situations where absence data were not available [175,178] and was widely used when working with combined data collected with different methodologies [178], as done in the present study. Maxent estimates the relative probability distribution of species occurrence by finding the probability distribution of maximum entropy, i.e., the distribution that is closest to uniform across the study area. The probability of occurrence can be interpreted as an estimate of the probability of the presence under a similar level of sampling effort as used to obtain the known occurrence data [271].

The following Maxent settings were chosen with regard to data limitations and the specific questions of the study [318]: i) logistic output to easily understand where the model predicts the occurrence of each cetacean species; ii) 30% random test percentage; iii) default regularization parameters, auto feature class types, and 500 maximum iterations; iv) 10-fold bootstrap replicated run type, a setting that allows replacement in sampling replicates and is particularly useful when the number of sightings are low [319]; and v) the maximum number of background points was 10,000 (over 43,800-369,861 available points) as number of background points greater than 10,000 does not improve the predictive ability of the model [271]. The maximum number of background points for two smaller regions (the SS and BB) was set to 1,720 and 320 respectively (~13% of its own available points, comparable to the average ratio of background-available points of other regions). Bias files were used to refine background point selection in Maxent. Bias files constrain the location and density of background point sampling to ensure that background points are generated from the same environmental space as the presence locations and allow the user to account for sampling bias from the data collection method [171]. Bias files were created and hence background selection was carried out using 30 km (15 km for two smaller regions: the SS and BB) buffered local adaptive convex-hull for individual species using the 'Background selection tool' in the SDMtoolbox 2.0 [316]. The buffers chosen have been shown to best restrict background point selection within the environmental space.

The performance of each Maxent model was evaluated using the AUC (area under the receiver-operating-characteristic curve), which assesses model discriminatory power by comparing model sensitivity (i.e., true positives) against model 1 minus specificity (false positives) from a set of test data [166]. The AUC value provides a threshold-independent metric of overall accuracy, and ranges between 0 and 1. An AUC value above 0.5 indicates that the model performs better than random [271], while values between 0.6 and 0.9 were indicative of a well fitted model [216]. To assess how much each environmental variable contributed to the Maxent run, jackknife tests of variable importance were conducted by running the model with-only and without a variable at a time. It was possible to evaluate the contribution (gain) of each variable with respect to the whole ensemble of variables, and to evaluate the effects of the lack of the selected variable on the model compared to the set of overall variables [178]. To distinguish suitable and unsuitable habitats, the 'maximum training sensitivity plus specificity threshold' was applied to the predicted distribution maps in ArcGIS 10.3. The mean threshold of 10 replicates of each species model was used as a binary threshold for presence/absence of corresponding species, above which a suitable habitat is considered to occur. This is the point where the proportion of correctly predicted presences and absences are maximised [320].

Maxent has a common problem with producing over-prediction, since it gives higher probability scores for habitat suitability in areas with similar environment characteristics to the sighting locations, although the predicted areas are located outside the observed range. To overcome the over-prediction, minimum convex polygon (MCP) with 30 km (15 km for two smaller regions: the SS and BB) as a buffer distance from the sighting point of each species was used in SDMtoolbox 2.0. This technique resulted in model outputs that represent the suitable habitat within an area of known occurrence, excluding potentially suitable habitats outside the observed range and unsuitable habitats throughout the study areas.

4.2.5. Species combined maps overlap with spatial conservation management system and anthropogenic threats

Firstly, a combined suitable habitat map (hereafter called 'combined map') was made by summing individual binary species suitability maps in each region [316]. This map, however, does not necessarily represent the absolute species richness [321] as only data from the selected 15 out of the 34 reported species was used. Next, the areal overlap between cetacean habitats and current spatial conservation management system was made by superimposing the combined map in each region with maps of MPAs and MSP jurisdiction. MPA polygons were gained from the Ministry of Marine Affair and Fisheries of Indonesia, while MSP jurisdiction (12 nm from coastlines [322]) was generated using 'Buffer-Analysis Tools' in ArcGIS 10.3. Similarly, to predict cetacean exposure to anthropogenic threats, the combined map in each region was overlaid with oil and gas concession areas and marine traffic, and the overlap between these areas was quantified. Oil and gas concession areas in Indonesia from Patra Nusa Data [323] were digitised in ArcGIS 10.3. Marine traffic was indicated by shipping density from a global map of shipping traffic [324].

4.3. Results

4.3.1. Maxent model performance

Maxent model performed well for the majority of species modelled for most regions. All model outputs presented good discriminant power with AUC scores ranging from 0.740 to 0.898, thus can be considered well fitted models. The standard deviation of the AUCs showed low values less than 0.05 for 29 out of total 33 model outputs (Fig. 4.2). The threshold values used to distinguish suitable and unsuitable habitats ranged from 0.302 to 0.555 (Supplementary Fig. S1). A comparison of suitable habitat from Maxent model predictions with the distributions of sightings shows a good agreement for most species in most regions (Supplementary Fig. S1). Of the 33 Maxent model outputs, six were performed based on only a few presence data points (between 10 and 15 data points) (Fig. 4.2).

4.3.2. Predicted distribution, important variables and habitat preferences

Our results reflected a great heterogeneity in distribution among species and within species among different regions (Fig. 4.2). Within the same region, predicted distributions varied between species and some species showed areas of overlap. The predicted distributions showed a similar pattern for overlapping species in a region, although differences in spatial extent were identified between species (Fig. 4.2).

Important variables differed across the model outputs for each species and region (Table 4.3). In general, bathymetry, distance to coast, distance to the −200m isobath, Chl-a, and SST were important variables for most species in many regions. High predictive scores or Habitat Suitability Index (HSI) of most species (Fig. 4.2) were mainly in areas that indicate the presence of these environmental predictors that represent productive areas. Habitat preference also varied among species (Supplementary Tables S2-S8). Below, the distributions of cetacean species, the important variables and habitat preferences are elaborated upon per region.

In the Sunda Strait (SS), both *Stenella longirostris* and *Tursiops truncatus*, were distributed near coastal areas, insular areas and around the −200m isobath, although *S. longirostris* was spread wider (Fig. 4.2). Distance to the −200m isobath was prominently determining the distribution of *S. longirostris* and *T. truncatus*. The second most important variable explaining the distribution of both species, however, differed; bathymetry for *S. longirostris*, and Chl-a for *T. truncatus* (Table 4.3). The habitat preferred by *S. longirostris* was characterised by being closer to the −200m isobath, and at areas with a depth of around −255m, and these characteristics were significantly different in comparison with habitat where the species did not occur (Supplementary Table S2). Similarly, the habitat preference of *T. truncatus* was related to areas closer to −200m isobath, but having higher Chl-a (Supplementary Table S2).

In the Balikpapan Bay (BB), the high predicted distribution of *Orcaella brevirostris* was principally found in river areas (Fig. 4.2), while *Tursiops aduncus* was distributed both in estuarine and coastal waters (Fig. 4.2). The distribution of *O. brevirostris* was mainly determined by SST and SSS, while the distribution of *T. aduncus* was dominantly explained by slope and SSS (Table 4.3). *O. brevirostris* preferred habitat that was characterised by higher SST and lower SSS (Supplementary Table S3). *T. aduncus* was likely to occur in areas with steeper sea-bottom slope and lower SSS (Supplementary Table S3).

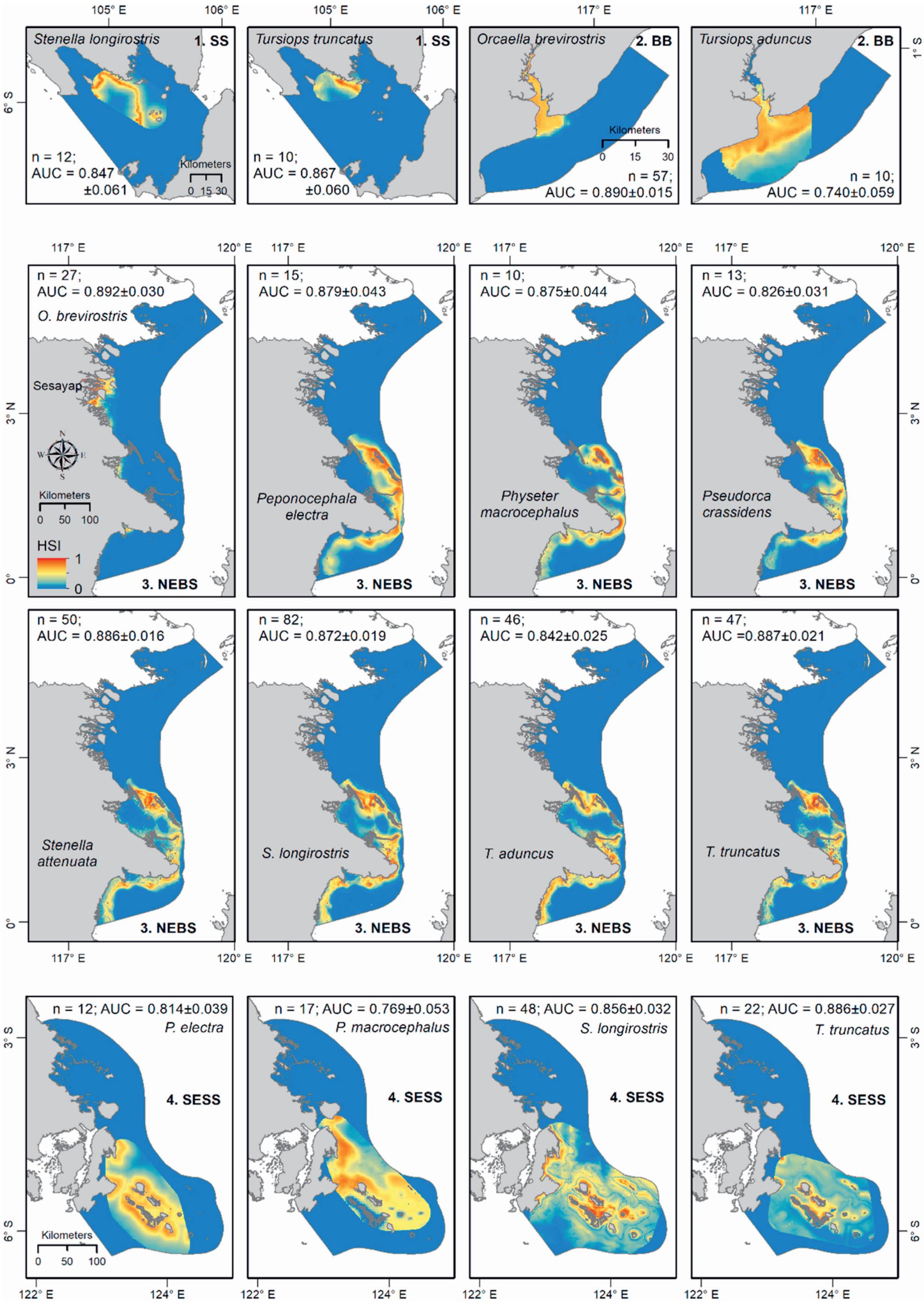

Fig. 4.2. Individual spatial distribution of 15 cetacean species in the 7 Indonesian regions included in this study (regions #1-4, regions #5-7 on the next page). Habitat Suitability Index (HSI) ranges from 0 (blue) to 1 (red). n = number of sightings, AUC is area under the receiver-operating-characteristic curve.

Chapter 4

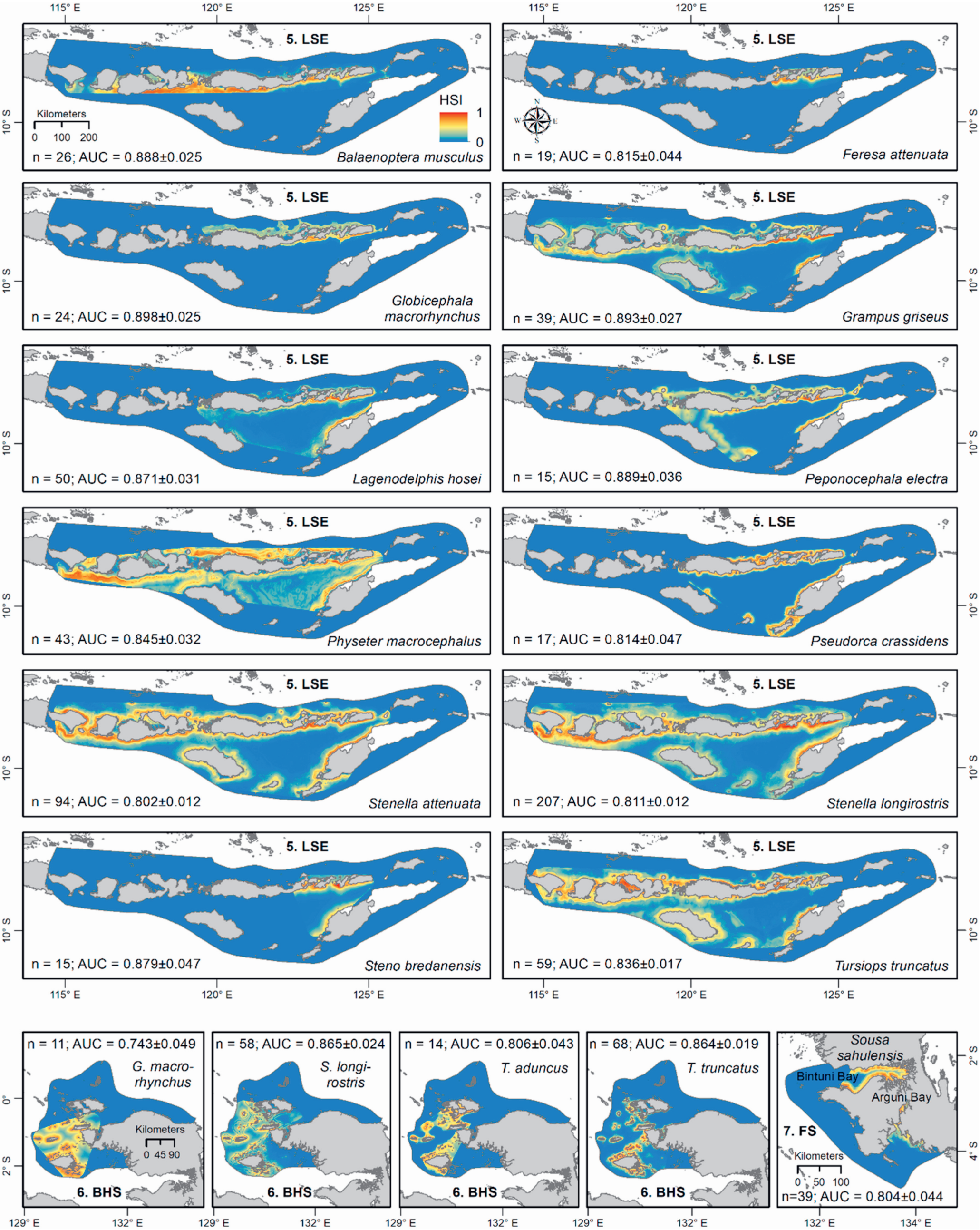

Fig. 4.2 (*continued*). Individual spatial distribution of 15 cetacean species in the 7 Indonesian regions included in this study (regions #5-7, regions #1-4 on the previous page). Habitat Suitability Index (HSI) ranges from 0 (blue) to 1 (red). n = number of sightings, AUC is area under the receiver-operating-characteristic curve.

Table 4.3. Relative importance (%) of each environmental variable in explaining the species distribution in the Maxent model. Bold numbers in grey background are the two most important variables, bold italic numbers with grey background are the third or the fourth important variables that were required to achieve a summed explanation of at least 50%. The variable names in the first row are the names given in Table 4.1.

	Bathy	Slope	d_200	d_1000	d_2500	d_coast	SST	SSS	Chl-a
Sunda Strait (SS)									
Stenella longirostris	**13**	4.8	**76.2**	3.2	-	0	2.7	-	0.1
Tursiops truncatus	0.4	3.8	**42.9**	4.9	-	14.5	6.9	-	**26.6**
Balikpapan Bay (BB)									
Orcaella brevirostris	7	4	-	-	-	-	**74**	**15**	-
Tursiops aduncus	12	**41.5**	-	-	-	-	13.3	**33.3**	-
NE Borneo Seascape (NEBS)									
Orcaella brevirostris	**13**	8.5	3	4.7	-	**56.6**	-	10.9	3.3
Peponocephala electra	12	3.5	**49.4**	15.7	-	1.2	-	1.5	**16.7**
Physeter macrocephalus	0.8	1.4	**27.3**	7.1	-	**53.1**	-	10.3	0
Pseudorca crassidens	0.9	**42.6**	12.6	4.3	-	16.3	-	5	**18.3**
Stenella attenuata	**17.2**	13.3	15.3	***16.3***	-	11.8	-	**17.3**	8.8
Stenella longirostris	**32.2**	7.6	5.6	14.6	-	12.6	-	6.4	**21**
Tursiops aduncus	**16.2**	12.8	5.5	5.4	-	**47.6**	-	6.9	5.6
Tursiops truncatus	***18***	12.7	6.2	6.6	-	**23**	-	12.1	**21.4**
SE Sulawesi Seascape (SESS)									
Peponocephala electra	7.4	5	**43**	10.2	6.2	-	**16.7**	9.5	2
Physeter macrocephalus	10.4	6.9	11.3	**15.6**	1.7	-	0.5	3.2	**50.4**
Stenella longirostris	10.3	11.3	***13.3***	**18**	7.8	-	***13.3***	11.6	**14.4**
Tursiops truncatus	**57.8**	4.2	4.8	6.4	5.2	-	***7.7***	7.4	6.5
Lesser Sunda Ecoregion (LSE)									
Balaenoptera musculus	**45.9**	5.4	4.4	4.3	2.1	-	12.1	8.7	**17.1**
Feresa attenuata	15.1	2.8	**33.3**	11.1	3	-	**17**	6.3	11.4
Globicephala macrorhynchus	**25.3**	6.7	12.9	***16***	7.6	-	7.1	5.5	**18.9**
Grampus griseus	**18**	8.9	**30.7**	10.1	9.4	-	5.1	5.4	***12.4***
Lagenodelphis hosei	**33.9**	2.5	**19.1**	4.9	12.6	-	1.1	11.5	14.4
Peponocephala electra	**25.9**	0.6	8.5	23.1	9.9	-	**26.7**	1.5	3.8
Physeter macrocephalus	***13.8***	9.9	6.7	**25.7**	12.3	-	**15.1**	10.3	6.2
Pseudorca crassidens	**32.6**	3.8	**56.8**	0	0	-	5	0.6	1.2
Stenella attenuata	**25.3**	7.9	***13.6***	3.8	12.5	-	8.8	11.4	**16.7**
Stenella longirostris	***16.9***	7.4	**19.8**	6.1	11.9	-	6.4	**19.9**	11.6
Steno bredanensis	11.8	3	**39.9**	11.7	0.2	-	**26.8**	2.3	4.3
Tursiops truncatus	**32.1**	4.2	14.5	10.2	4.1	-	**18**	2.9	14
Bird's Head Seascape (BHS)									
Globicephala macrorhynchus	5	0.2	12.9	-	0.9	**29.3**	**50.4**	-	1.3
Stenella longirostris	8.5	8.1	**12.1**	-	8.4	**40.7**	12	-	10.2
Tursiops aduncus	**68.3**	5.1	6.9	-	1.3	**16.4**	1.1	-	0.9
Tursiops truncatus	**14.3**	4.4	6.8	-	4	**53.4**	8.6	-	8.5
Fakfak Seascape (FS)									
Sousa sahulensis	**19.1**	12.3	-	-	-	**61.4**	4.2	3	-

- : predictor was not used in modelling either due to its unavailability in the region, or was removed due to multi-collinearity

In the NE Borneo Seascape (NEBS), the predicted distributions were almost identical for all species and present in broader areas (Fig. 4.2), except *O. brevirostris* which was restricted to estuarine areas like in the BB. Most of the delta areas of the NEBS were predicted to be a suitable habitat for *O. brevirostris*, especially in Sesayap in north areas (Fig. 4.2). This prediction will need to be validated in future surveys. Areas that consistently indicate high habitat suitability for the other species were in coastal and complex insular-reef areas. High suitability predictions also extended towards the southern part of the region along the coastline. Bathymetry, distance to coast and Chl-a were the most important variables determining the distribution of most species (Table 4.3). The distribution of two deep diving species, *Peponocephala electra* and *Physeter macrocephalus*, in addition was explained by distance to the −200m isobath. The habitat preferences of all species in the NEBS are detailed in Supplementary Table S4.

In the SE Sulawesi Seascape (SESS), the model suggested that *P. electra* and *P. macrocephalus* have a wide distribution (Fig. 4.2), with *P. macrocephalus* tending to avoid shallow reefs. *S. longirostris* occurred closer to the complex insular-reef areas, while *T. truncatus* was occupying both coastal and complex reef areas (Fig. 4.2). Some patches of predicted high suitability for *S. longirostris* and *T. truncatus* occur in the vicinity of oceanic islands. Environmental variables that explain most of the distribution of each species are given in Table 4.3. The two most important variables for *P. electra* were distance to the −200m isobath and SST. Chl-a and distance to the −1000m isobath were the major predictors that determined the distribution of *P. macrocephalus*. The distribution of *T. truncatus* was well-explained by bathymetry and SST. *S. longirostris* distribution was determined by four most important variables, i.e., distance to the −1000m isobath, Chl-a, distance to the −200m isobath, and SST. The preferred habitat areas of these species can be found in Supplementary Table S5.

In the Lesser Sunda Ecoregion (LSE), all species exhibited relatively uniform spatial distributions, concentrated along the coastal areas with the differences in spatial extents (Fig. 4.2). Areas with relatively low occurrence, so relatively unsuitable for most species, were in deeper oceanic waters. Two species, *P. macrocephalus* and *P. electra* however, were predicted to occur in deeper oceanic waters, although with low predicted values. For most species, two topographic variables, bathymetry and distance to −200m isobath, and two oceanographic variables, SST and Chl-a, were the most important variables (Table 4.3). The distribution of two deep diving species, *Globicephala macrorhynchus* and *P. macrocephalus*, was also explained by distance to the −1000m isobath (Table 4.3). *Steno bredanensis* is a regular inhabitant of coastal waters, but it was also found around the −200m isobath. The habitat preferences of all species in the LSE can be seen in Supplementary Table S6.

In the Bird's Head Seascape (BHS), the predicted distributions were relatively homogeneous and predicted mixed-species distribution overlap, although there was spatial variability among species (Fig. 4.2). Areas suggested as favourable habitat for all species were dominated by coastal and complex insular-reef areas. Distance to coast and bathymetry were two major environmental variables that drove the distribution of most species. The habitat preferences of the species occurring in the BHS can be found in Supplementary Table S7.

Finally, for the Fakfak Seascape (FS), the model showed *Sousa sahulensis* to principally utilise estuarine areas. Two main estuarine areas with consistently high predicted distribution of *S. sahulensis* were the Bintuni Bay and the Arguni Bay (Fig. 4.2). Areas further offshore seem to be less suitable for the species. The distribution of *S. sahulensis* were determined by distance to coast and bathymetry (Table 4.3). The preferred habitat of *S. sahulensis* was closer to coast in areas with depths around −23m (Supplementary Table S8).

Habitat preferences of same species in different regions

Our modelling results show great heterogeneity in within-species habitat preferences among different regions. Nine out of 15 species occurred in more than one region (Fig. 4.2). The distribution of *O. brevirostris* mainly occurred in river and estuarine areas both in the BB and the NEBS. The other species that were present in more than one region did not show consistent habitat preferences. For instance, *P. macrocephalus* was associated with more complex insular-reef areas in the NEBS, utilised more coastal areas in the SESS but avoided shallow reefs, and occupied both coastal and deeper waters in the LSE (Fig. 4.2). The heterogeneity in distribution for other species that occurred in more than one region can be seen in Fig. 4.2.

4.3.3. Combined species maps and overlap with management systems and threats

Maxent results can be reported as probabilities or binary output (i.e., suitable vs. unsuitable habitat). The latter is easier to interpret and has important implications for managers to define areas of interest. The individual suitable habitat maps for each species in each region are shown in Supplementary Fig. S1. The combined suitable habitat map of all species (hereafter, the combined map) in each region shows distinct patterns, with most used common locations along coastlines and complex insular-reef areas (Fig. 4.3). The hotspots based on the combined maps were identified in each region, and most prevalent in the NEBS, SESS, LSE and BHS (Fig. 4.3). In the NEBS, SESS, and BHS the hotspots can be found around complex insular-reef areas, while in the LSE two hotspots were identified in coastal areas (Fig. 4.3).

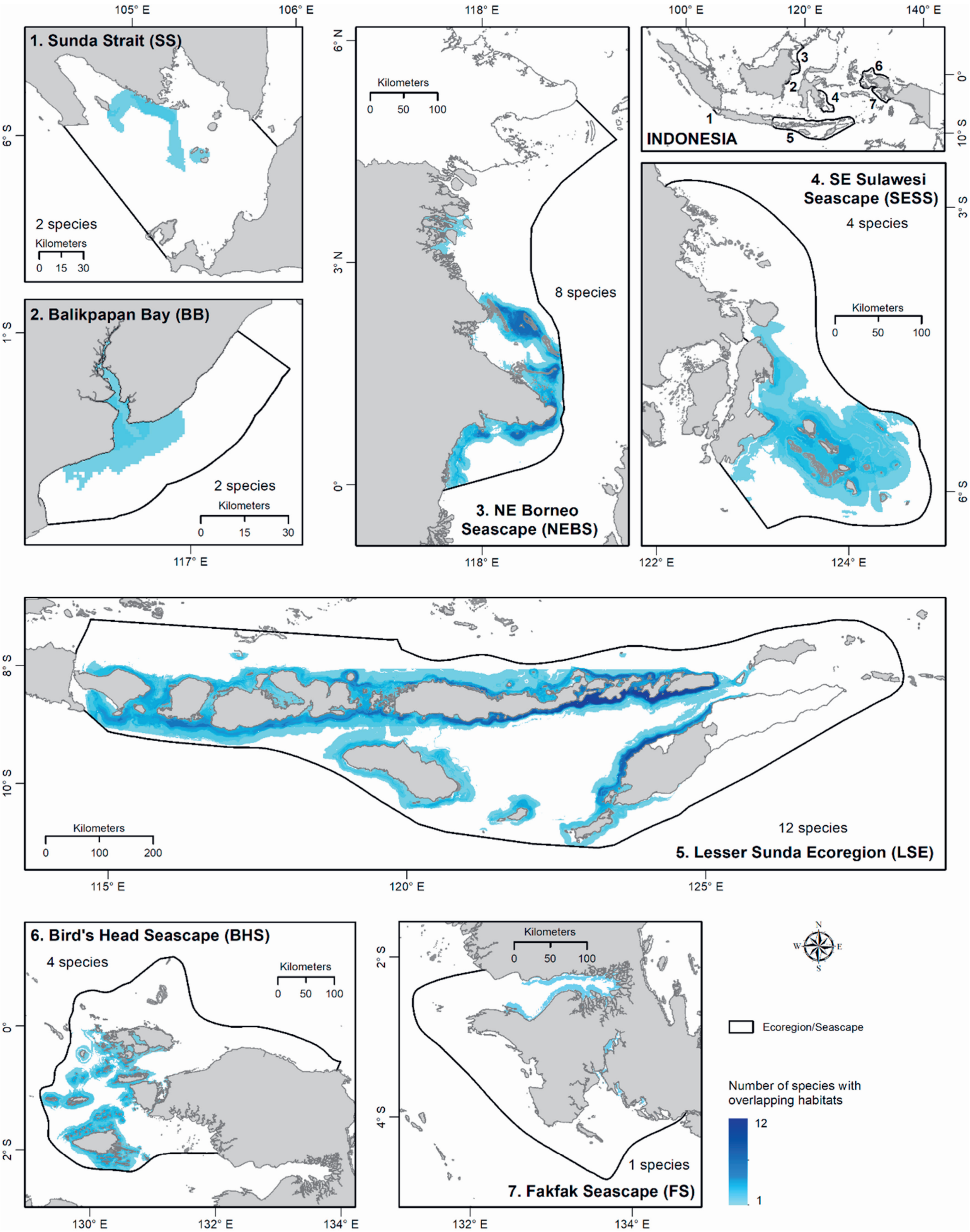

Fig. 4.3. The combined suitable habitat maps of all modelled species in each of 7 regions in Indonesia. The number of overlapping species habitats are different in each region.

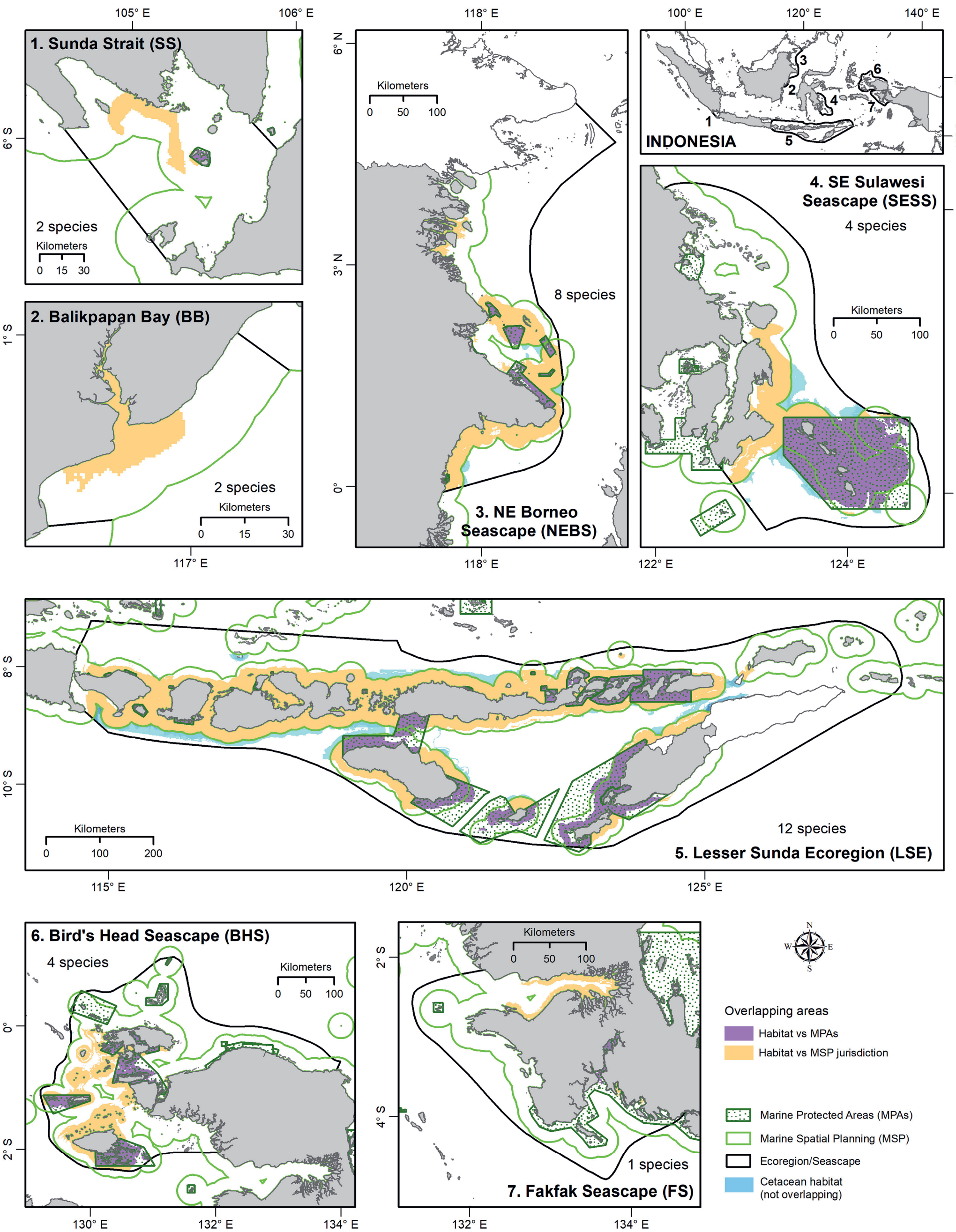

Fig. 4.4. Overlapping areas between the combined suitable habitats (from Fig. 4.3) with Marine Protected Areas (MPAs) and Marine Spatial Planning (MSP) jurisdiction. Purple areas are the cetacean habitats that fall within an MPA (dark green dotted areas), while ochre areas are the habitats that fall within an area under MSP jurisdiction (light green lines). The black lines indicate the area included in the modelling (ecoregion or seascape).

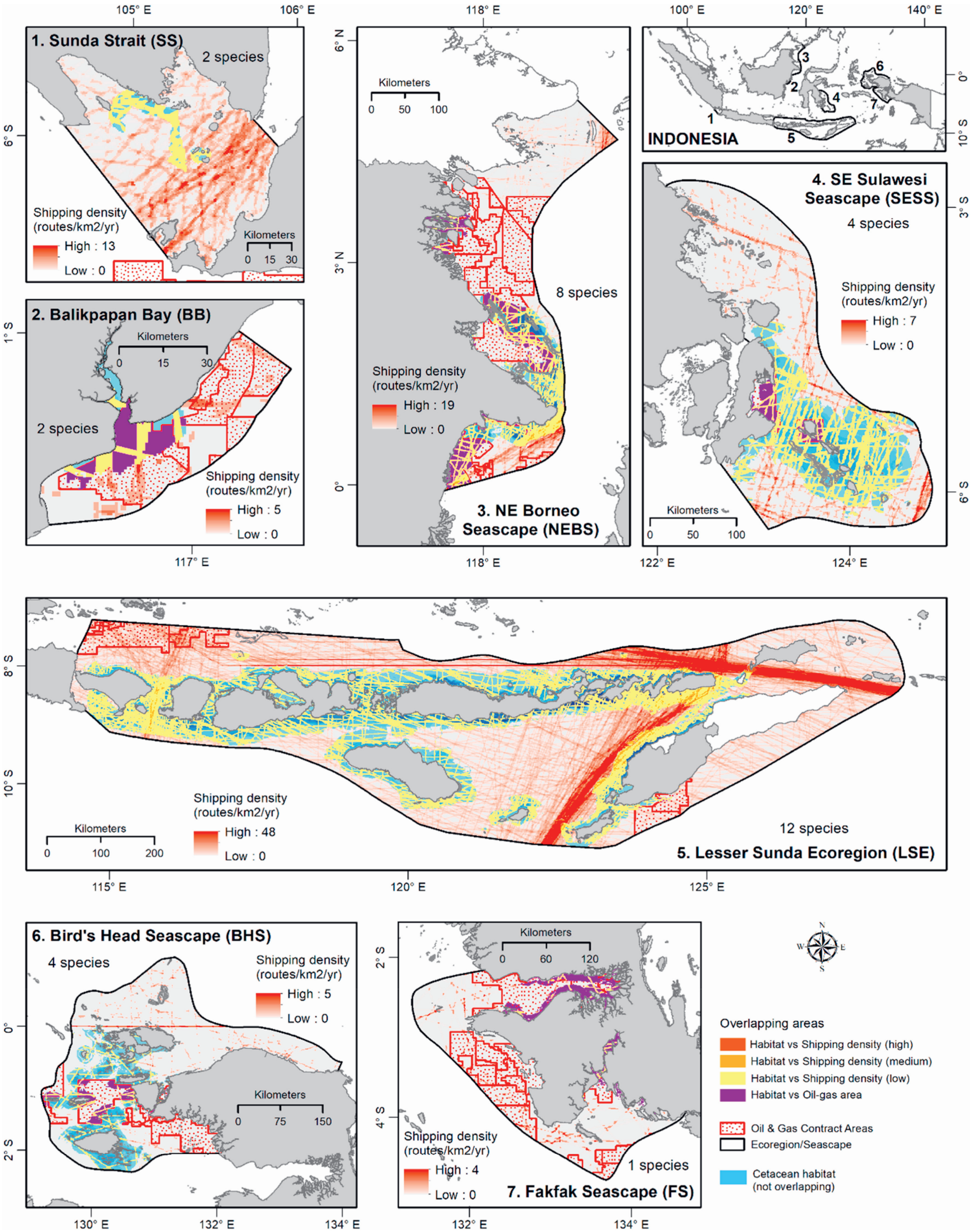

Fig. 4.5. Overlapping areas between the combined suitable habitats (from Fig. 4.3) with two anthropogenic threats: shipping traffic (shipping density of large vessels (>300 tons) indicated with gradual red colours, data from Halpern et al., 2008), and oil & gas contract areas (red dotted). In dark orange areas, the cetacean habitats overlap with high shipping intensity (14-48 routes/km^2/yr). In orange areas, the habitat overlap with medium shipping intensity (8-13 routes/km^2/yr). In yellow areas, the habitat overlap with low shipping intensity (1-7 routes/km^2/yr). In purple areas, the cetacean habitats overlap with oil-gas contract areas.

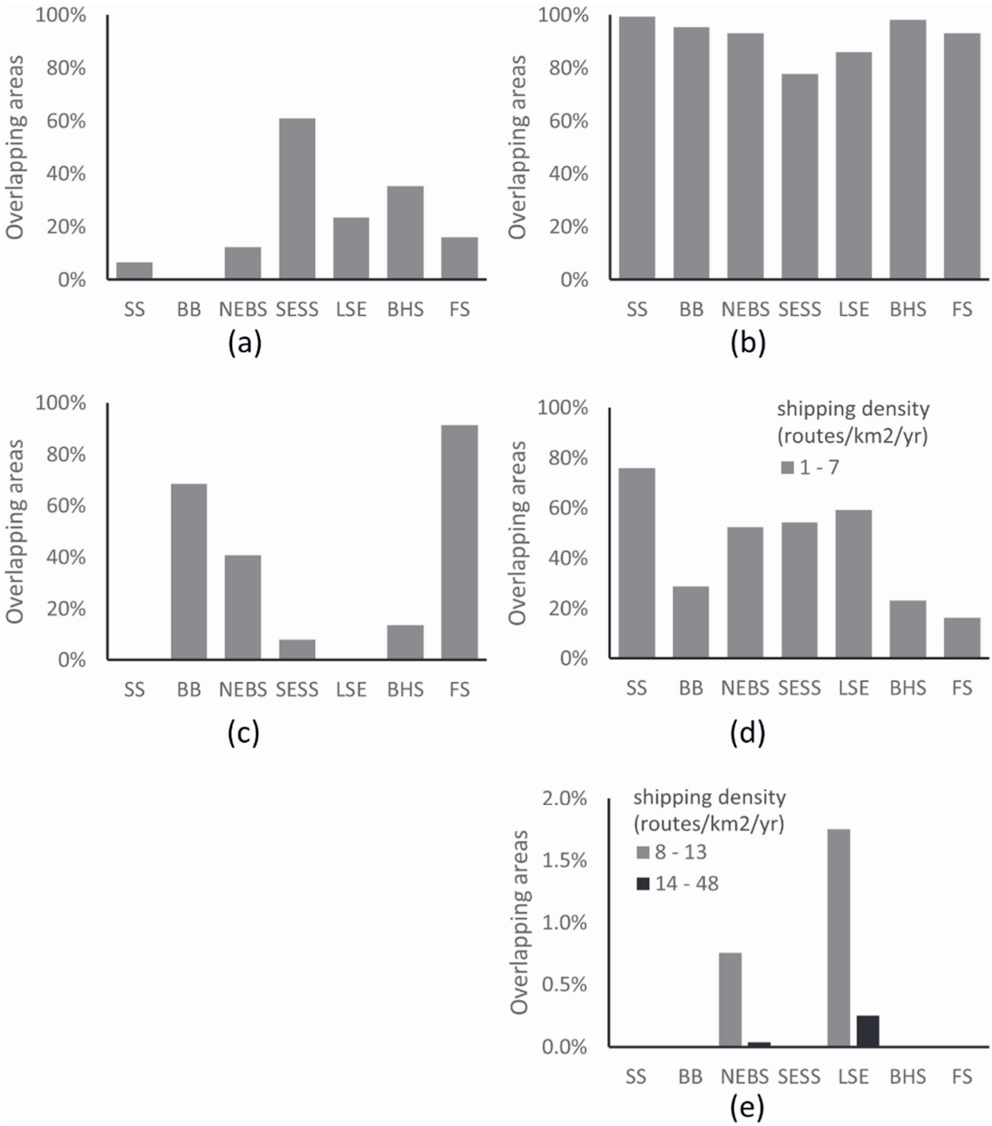

Fig. 4.6. The percentage of local cetacean habitat that overlap with: (a) MPAs, (b) MSP jurisdiction waters, (c) oil-gas contract areas, (d) low shipping density (1-7 routes/km^2/yr), and (e) medium (8-13 routes/km^2/yr) and high (14-48 routes/km^2/yr) shipping density in the 7 Indonesian areas modelled in this study. SS=Sunda Strait, BB=Balikpapan Bay, NEBS=Northeast Borneo Seascape, SESS=Southeast Sulawesi Seascape, LSE=Lesser Sunda Ecoregion, BHS=Bird's Head Seascape, FS=Fakfak Seascape.

Superimposing the combined maps with MPAs and MSP jurisdiction indicate areas of potential future protection. Some highly suitable areas were outside protected areas where multiple human activities are allowed and only ≤35% of these areas were covered by MPAs (except in the SESS with 61% of the suitable areas fall within MPAs; Figs. 4.4 and 4.6a). Still, the majority (≥78%) of these suitable areas will potentially be covered in the MSP jurisdiction (e.g. in the SS, BB, NEBS, LSE and BHS; Figs. 4.4 and 4.6b), therefore it is important to take these critical habitats into account during MPA and MSP designation. In addition, superimposing the combined maps with the anthropogenic threats indicate areas of high potential risk. Some suitable habitats coincide with oil and gas exploration areas and marine traffic (Figs. 4.5 and 4.6c-e). The majority of areas with predicted high habitat suitability had low risk from shipping traffic (BB, NEBS, SESS, BHS, and FS; Fig. 4.5 and 4.6d,e). The LSE and SESS have large areas with suitable habitats overlapping with MPAs (Figs. 4.4 and 4.6a), and less overlapping with oil and gas concession areas (Figs. 4.5 and 4.6c). The LSE, however, and the SS have more dense shipping lanes. The overlap between suitable cetacean habitat and medium and high shipping density is ≤2% (Fig. 4.6d and e), suggesting that cetaceans face relatively substantial risk in these regions. Remarkably, several MPAs also overlap with oil & gas concession areas in five regions: the NEBS, SESS, LSE, BHS, and FS (Figs. 4.4 and 4.5). The rest of the overlapping areas are considered to have low exposure to the two studied anthropogenic threats (Supplementary 2 Table S9).

4.4. Discussion

The current knowledge of cetacean spatial distribution, its protection coverage and anthropogenic threats in Indonesia is still very limited though crucial for effective conservation management. Here we present the distribution modelling of 15 species in seven ecoregions or seascapes in Indonesia at a 1 km^2 fine spatial resolution. The results reveal partial overlap with current MSP and MPA management systems and conflicts with anthropogenic activities. This study is a first attempt to provide more comprehensive spatial information using a currently available large collection of cetacean data. We summarise the main findings and general patterns, highlight remarkable results, and provide the full information in the supplementary. Below we discuss (i) the spatial distribution resulting from the models, (ii) the quality of the models and their limitations, and (iii) the combined map and overlapping areas, as well as the potential uses of the model outputs, its implications for national cetacean conservation management and future perspectives.

4.4.1. Spatial distribution and habitat suitability predictions

Great heterogeneity in spatial distribution and habitat preferences among species and within species among different regions was identified from our work (Fig. 4.2). It is not surprising taking into account the different ecological niches of the 15 species. For cetaceans, utilizing spatially different habitats may be a strategy to minimise interspecific food competition [325]. The heterogeneity reflects an interrelated influence of both topographic and oceanographic variables on the distribution of cetacean species. Both variables play a major role in partitioning the distribution of cetacean species, underlining how these variables were employed in the Maxent model to predict species distribution [262]. The predictions reflect species' traits in how they use the habitat. The fine scale of the present study allows us to identify habitat use and preferences in relation to different environmental features.

The species-specific habitat preferences of cetaceans are reflected in the set of environmental variables selected by each species' model output. Both the composition and the number of environmental variables that determine habitat preferences, as well as the relative importance of the respective variables, are species-specific (Table 4.3). Each species in most regions mainly had 2 important variables determining its habitat that thus were retained in its model. Only *S. longirostris* in the SESS had 4 variables, the highest number of variables, retained in the model compared to other species model outputs (Table 4.3). Four other species in the LSE and 2 species in the NEBS also had 3 important variables. The high number of variables retained in the models indicates that their environmental niche in the region depends on the combination of several conditions. Despite the different important variables across the model outputs for each species and region, in general, Chl-a and SST (oceanographic predictors), and bathymetry, distance to coast and distance to −200m isobath (topographic predictors as proxies for productivity), were the most important variables that contributing to the distribution of most species in many regions. To a lesser extent SSS and distance to the −1000m isobath were important for respectively estuarine and oceanic species. The ecological interpretation of complex relationships detected through Maxent model, of course, needs further analysis and validation.

Chlorophyll-a as a proxy of high productivity areas

Areas with high predictive suitability in every region were mainly related to coastal areas or insular-reef complexity. In general, suitable habitat seems chiefly associated with high productivity, often with upwelling-modified waters close to the topographic features [185], which would create favourable foraging conditions. It has been reported before that cetacean distributions and population densities reflect the oceanographical conditions that are associated with biological productivity and diversity hotspots [279,326–328]. That is why most suitable habitat areas identified in our results are mainly characterised by chlorophyll-a concentration (Chl-a) and sea surface temperature (SST), and for a few species by sea surface salinity (SSS) (Fig. 4.2, Table 4.3). Chl-a indicates phytoplankton and is the basis of the food web and is driven by nutrient availability (for example from rivers, and thus related to lower SSS) and higher SST [329]. Therefore, it works as a good proxy for other bio-ecological factors [258] such as the distribution of zooplankton feeding on the phytoplankton on which the next predators feed including the prey species for the cetaceans. Thus, via this indirect link between primary biomass as represented by Chl-a and cetacean occurrence, Chl-a seems useful in identifying hotspots where cetaceans may aggregate. Our results are in accordance with Cotté et al. [217] and Putra and Mustika [330,331] who reported that densities of dolphins were related to high Chl-a and high gradients of SST. All study areas are situated in the Indonesian tropical upwelling system, where oceanic currents strongly influence the temperature and primary productivity [73,74], benefitting marine species at all levels of the food web, including cetaceans. All of our determinants do contribute to the features of productive habitats (Chl-a, SST, SSS, depth, slope), thus the determinants resulted from this study may not be applicable to oligotrophic areas in Indonesia and thus should be studied further. The distribution of some species (e.g., *S. sahulensis* in the FS and three species in the BHS), however, seemed not related to primary production but was instead strongly influenced by topographic variables (mainly distance to coast and bathymetry).

Topographic complexity indicating high habitat and prey diversity

Our model outputs clearly show that most species occurred in more complex topographic areas such as complex reefs and oceanic insular areas identifiable by certain depth e.g., the −200m and −1000m isobaths, and in a few species by slope. In the NEBS and SESS, for instance, sperm whale distribution is closely associated with the −200m and −1000m isobaths. The latter isobath was also reported as a key determinant of sperm whale occurrence in the past [192]. Distance to the −2500m isobath, however, was not retained in any model output as an important variable, indicating that this variable is weak in determining cetacean distribution. Topographic variables have been suggested to influence and even drive persistent hydrographic features which can lead to the creation of predator hotspots [268,294,298] and most likely affects the availability, distribution and concentration of prey species [332,333]. The high topographic heterogeneity areas and sea currents result in formation or localised upwelling, stimulating primary productivity that can sustain a rich food web structure and contain dense patches of prey, attracting large predators [216], including cetaceans. Blue whale in the LSE was predicted to be distributed in deep yet near coast areas around the strait between Flores and Sumba islands (Fig. 4.2). This is in agreement with Ilangakoon and Sathasivam [334] suggested that blue whales can be present in relative small, localised highly productive feeding area associated with strong upwelling year-round in Sri Lanka, and only make localised movements within this area. *O. brevirostris* prefers shallow, sheltered estuaries, such as in the NEBS, since such areas are commonly highly productive systems that can attract fish and top predators [58]. It has been shown before that distinct isobaths (−200m and −1000m) are important factors in determining the distribution of many cetaceans known to forage on pelagic schooling fish or deep-water prey [327,335]. In our study, especially the LSE, NEBS and SESS have very steep slopes with bathymetry exceeding −1000m within a short distance from shore. Near-shore deep waters with complex topographic is supportive of high cetacean diversity.

Species traits reflected in their predicted distribution

Cetaceans greatly differ in traits such as food choice, body surface-volume ratio and physiological adaptations for deep diving to forage [336]. For instance, *P. macrocephalus* and *G. melas* have lower energetic costs and are able to forage deeper than most delphinid species and therefore can exploit deeper food resources along the continental slope than species with shallower diving capabilities [336]. Predicted habitat from our study was also higher for most species in coastal (mainland or insular) areas. Cetaceans increase their benefits by spending as much time as possible close to the areas where the likelihood of finding their preferential prey may be higher [329]. For instance, bottlenose dolphins in all regions prefer coastal areas in which have shallower feeding grounds that often host complex and rich food webs [329], which is optimal for a species that chiefly forages on demersal prey [337].

The same species can have distinct habitat preferences in different regions and the combination of different environmental variables may influence its predicted distribution. The expression of the combination of variables can be unique in each ecosystem [185]. Our results showing that sperm whales can inhabit different areas with variable characteristics are in agreement with those reported by Praca et al., [298], since some cetaceans tend to be opportunistic towards their surrounding available habitats. In this case, sperm whale can sustain their needs in both productive coastal and complex insular-reef areas, as well as in more offshore oligotrophic areas [266]. Comparison of the habitat preference of a species over different regions characterised by different complex environmental variables could add understanding on the core qualities of the species' favoured areas. Habitats overlapping for different species are especially important to study further as understanding co-occurrence due to niche specialisation as well as potential interspecies competition better might be very helpful for cetacean conservation management effort.

4.4.2. Quality and limitations of the models

To be able to build a plausible habitat suitability model, we carefully analysed data, performed predictor quality control (e.g., reducing data autocorrelation and environmental variable multicollinearity) [316], chose Maxent as it is specifically designed to handle presence-only data [166,178], and corrected over-prediction model outputs [316]. Model evaluation metrics (based on moderate-high AUC and low SD values) indicate that most of model outputs had internal model consistency, thus supporting the reliability of models, and the distribution models produced had reasonable robustness [325]. The results are useful not only for ecological investigation but could also support conservation management decision making. Nevertheless, in the interpretation of model outputs attention should be paid to some methodological limitations. Some common issues derived from sample size, different sources of data, sampling bias and different spatial scales could influence the accuracy of the Maxent algorithms [178] and are discussed below.

The sighting data used in this study was collected opportunistically in areas of known occurrence or areas that are easy to survey, hence our sighting data represents a sampling bias (Fig. 4.1). Spatial autocorrelation, the tendency of locations close to one another sharing similar values for environmental variables, is also common in species occurrence data [338]. This can lead to a number of problems in species distribution modelling, including biased coefficient estimates, inflated measures of model evaluation and difficulties in transferring predictions in geographical space [339]. Spatial autocorrelation arises from several processes, but mainly by sampling bias [340]. To correct for non-homogeneous distribution of the sampling effort [171], we tried to address this issue by applying the 'bias file' function in the Maxent models [316,321].

Due to sample size limitations, we only modelled the habitat suitability for 15 out of 34 cetacean species in seven regions in Indonesia (Fig. 4.2, Supplementary Table S1). Obtaining enough data for modelling the habitats of cetaceans, or top predators in general, is challenging because these organisms are by nature sparsely distributed compared to lower trophic levels, and their detection is often imperfect, often resulting in scarce datasets [191]. We performed the distribution models, despite the relatively small number of sightings for some species, as a useful first approach of cetacean habitat modelling that could accelerate the knowledge on distribution of these never-studied populations. A number of previous studies also successfully used distribution models for multiple cetacean species with low numbers of sighting records (e.g., [216,287,341]). For some species in our study, the number of sightings unfortunately was too low (between 10 and 15 points) for our distribution modelling, highlighting the need for further dedicated monitoring of cetacean presence in this area to validate the predicted distributions from the models and also to build better databases for future modelling works.

Among available presence-only models, we chose Maxent because it appeared more suitable to model the predictions of species distribution with complex interactions between the response and the predictor variables [175,271] and seemed to manage datasets characterised by scarce data well [313]. The use of Maxent along with limited occurrence data, can be a cost-efficient way to obtain information for unprecedented studied regions. Ideally, the number of occurrence data point is >15 sightings to prevent inconsistent model results [342], although Maxent is known to perform well with small sample sizes [343], which was the case for several species in our study. More sightings over the whole year can generate seasonal predicted distributions for species by incorporating seasonality into future models, which is especially relevant for non-resident species. Despite the aforementioned limitations, our results provide crucial first insights to support conservation and management strategies where there was a fundamental lack of knowledge regarding cetacean distribution.

4.4.3. Overlapping suitable habitats and conservation management areas and threats

This study highlights the importance of several ecoregions and seascapes in Indonesia for cetacean species especially in the LSE and NEBS, while several species could not even be included due to insufficient data. The more species that occur in a region, the more important the region from conservation perspective [344]. Most of the important coastal habitat areas also containing major human settlements, harbours and tourism destinations. These anthropogenic activities pose actual and potential future threats to cetacean populations in those regions. The combined species maps also show that important suitable cetacean habitat is in the vicinity of insular areas. Understanding the current habitat use of cetaceans is a necessary step in comprehending and evaluating the effects of human activities on the species for conservation management strategies including MSP and MPA. In spatially explicit risk assessments, local species distribution should be linked to the potential effects and distribution of human activities [345]. Measures can then be developed to reduce or avoid the adverse impacts. This study provides cetacean distribution maps at a fine (1 km^2) resolution as an input for MSP to promote human activities that are less harmful to cetaceans [341].

Using Maxent modelling to identify cetacean suitable habitat can provide the scientific justification for their more effective protection. Our results show that large areas of important cetacean habitats are currently not protected in the existing conservation management system, since areas of highest probability were located outside MPAs (Fig. 4.4). These areas could to be considered in other site-based protection approaches such as MSP development [304]. The information on spatial gaps in protection coverage is useful to assess effectiveness of existing MPAs for conserving biodiversity in the region. To our knowledge, no studies so far have investigated whether Indonesian MPAs are adequately protecting marine mammals, which is the ambition of the Indonesian government [308]. The different extent of species habitats making the delineation of MPAs a challenge. The most suitable cetacean habitats in coastal and complex insular-reef areas deserve special protection against human activities that may threaten cetaceans and deserve special attention when establishing MPAs. Typically, small MPAs offer limited conservation benefits [346] particularly for mobile species. Additional measures to protect the migratory species are needed including restrictions on fisheries activities with destructive gears in the species hotspots, seasonal closures during migration and breeding seasons and temporal or permanent ship rerouting [1,310,347]. The size and design of MPAs and consequent management measures should be adapted to the ecological principles of the cetacean life cycles and that of their prey [348]. MPAs also need to be viewed in the larger context of the entire ecosystem including the extent to which these habitats interact at larger spatial scales [262]. In Indonesia, provincial MSP jurisdiction only covers waters until 12 nm from the coastline. Thus, to improve the protection of cetaceans outside current MPAs and provincial MSPs, the suitable habitats should be taken into account in MSP establishment in waters beyond 12 nm [349]. The existing knowledge on cetacean habitats in this region, fortunately, has been largely included as Important Marine Mammal Areas (IMMA) [350]. In addition, the ecosystem in which marine mammals live often encompasses the waters of more than one country [351]. This is the case in the LSE, where two countries (Indonesia and Timor Leste) share the coastline, therefore can encourage multi-national collaborations, for instance through the Coral Triangle Initiative (CTI), since both countries are the members of CTI. Our results allow the identification of the suitable habitat for the species over wider areas, providing the means to strengthen protection for the species beyond individual country's territorial waters.

Worldwide, oil-gas exploration is currently expanding into areas previously undisturbed by industrial development [352], including areas important for cetaceans. The BB and NEBS in East Kalimantan, and the FS in Papua hold significant hydrocarbon reserves and are well-known as important national oilfields [323] that can support the national need on oil, gas and income. The areas overlap with important cetacean habitat identified from our study. The concession areas are subject to seismic activity for hydrocarbon deposits in the seabed during exploration activities. Cetacean mass stranding events have been related to seismic exploration [353,354]. Seismic survey is also one major contributor of anthropogenic ocean noise [355,356] that cetaceans are exposed to [252,357], in addition to the noise produced by marine shipping. Although some cetacean suitable habitats overlap with oil-gas concession areas, Indonesia has no regulation on underwater noise such as from seismic activities [308]. Oil spills from exploration and production activity have been reported to cause massive pollution to the marine environment [356,358]. Cetaceans suffer from oil spills by direct contact with crude-oil or high concentrations of volatile gases, by indirect exposure to toxic oil hydrocarbons via their prey or loss of prey, as well as from oil spill response activities including increased vessel operations, dispersant applications, and oil burns [359,360]. The cetacean habitat maps from this study identify potential overlapping areas of conflict, which could be avoided. Where potential threats are already well known, such as near production wells for oil and gas extraction, enhanced preparedness for spill events in proximity to species habitat is also worthwhile.

Shipping is one of the world's largest industries and dominates ocean use [361], thus excluding this sector from decision-making could lead to increased conflict among user groups and negative environmental impacts [97,304]. This marine transport may directly affect the habitat use of marine mammals, since they coincide in the overlapping ocean spaces, and if uncontrolled, can create adverse impact to the species by collision and noise pollution. The overlapping maps of suitable habitat and shipping density from our study showed two regions, the SS and LSE, had high exposure of marine traffic (Figs. 4.5 and 6d), therefore mitigation for the anthropogenic threats should be focused on these areas. Within Indonesian waters, three archipelagic sea lanes (Indonesian: *Alur Laut Kepulauan Indonesia*, ALKI) have been established, i.e., in Sunda Strait (ALKI I), Lombok Strait (ALKI II), and Ombai Strait (ALKI III). ALKIs are one of the busiest shipping routes in the Asia and Oceania regions with an estimated 27% of the world's oil traffic per day are transported through the Malacca Straits and the ALKIs [362]. Although some cetacean suitable habitats exist close to the designated ALKIs, Indonesia has not declared any sensitive areas to protect such habitats from possible ship collision, noise and oil pollution produced by shipping operations. The current shipping also is not only concentrated in the established lanes, but also occurs in unofficial shipping lanes northeast of the ALKI III (Fig. 4.5). These lanes are also important migratory corridors for a variety of marine mammals including pygmy blue whale as shown by telemetry data [76]. During 1975–1997, oil spills from 104 shipping accidents polluted the Indonesian marine and coastal areas [363]. A better understanding of the shipping intensity overlapping with cetacean habitat can be used to inform ecosystem-based management within an MSP framework [304]. For instance, the information can be useful in planning low-impact shipping corridors, informing the delineation, modification or adjustments of the shipping lanes and additional protection needed for cetaceans by establishing new marine reserves [163,310].

It is important to note that the spatial footprint of marine traffic used in this study was only based on large vessels, so an underestimation of the shipping intensity. As mandated by the International Maritime Organization (IMO), only large vessels (>300 tons) making international voyages and all passenger ships regardless of their size are required to have an Automatic Identification System (AIS) to track their movements in real time [364]. Small recreational boats do not have AIS transmitters and can exist unnoticed in large numbers in certain areas. Vessel Monitoring System (VMS) data from fishing vessels unfortunately is not yet publicly available in Indonesia. Therefore, our marine traffic information excludes a large portion of smaller vessels, many of which travel a lot. Furthermore, these smaller vessels tend to operate inshore which will particularly affect exposure for the cetaceans which have been shown to prefer shallower coastal waters. Further work on improving our knowledge of the spatial distribution of inshore marine traffic is imperative and will give new insights into possible boat collision and noise risk.

4.4.4. Applications for national cetacean conservation and management, future perspectives

The risk exposure maps (Figs. 4.4 and 4.5) from our study can support management decisions and conservation measures as in MSPs, although they are only one input into a systematic conservation planning process [118]. Our analysis only included two anthropogenic threats: marine shipping and oil and gas industry. Fisheries, tourism and many more human activities are synergistically or individually also important anthropogenic threats to cetaceans [186,365]. More accessible information is needed to better understand the actual allocation of these other anthropogenic threats and the overlap with cetacean distribution, MPAs and MSP. The present study is an important step as a basis for assessing the overlap between cetacean habitat, anthropogenic threats, MPAs and MSP. Although bycatch is not included in our overlays, we suggest our approach should be used for bycatch mitigation as well, for Indonesia has a potentially prominent tuna gillnet fisheries in the Indian Ocean [366]. The cetacean spatial prediction maps as presented here provide a basis for valuable planning tool in the context of anthropogenic threats, and can also direct additional monitoring effort to further improve the spatial and species coverage. The inclusion of other anthropogenic pressures is a next step to better understand how human activities overlap with cetacean distribution and to determine where MSP for conservation management is urgently needed. Quantifying spatial risk assessment by using models such as INVEST [367] may also be a valuable and logical next step to this preliminary work.

4.5. Conclusion

The cetacean distribution maps presented here provide a recent habitat preference characterisation of the studied species. Closer analysis clearly indicates why Indonesian waters are rich in cetacean diversity, as topographic and oceanographic factors favour primary production and habitat complexity including deep waters. We provide fine resolution distribution maps of 15 cetacean species in seven regions in Indonesia. We highlight the areas of highly suitable cetacean habitat as priority areas for future spatial conservation decisions, for example, in the SS, the BB, the northern part of the NEBS, and the north-eastern part of the LSE. Our results also identified potential areas of conflict with human activities. High risk areas will vary with seasonal distribution, further research on seasonal modelling is then needed e.g., to find the best time for performing oil and gas exploration (seismic activity). It is important to realise that 19 out of the 34 species reported were not included in this modelling study because of lack of sighting data. The distribution of these species should also be taken into account in future cetacean conservation management planning.

The spatial planning efforts should also include a larger spatial scale than 12 nm to ensure all important biodiversity assets are appropriately represented in new MPAs, in protected zones within provincial MSP jurisdiction, or in future open-sea MSP establishment beyond 12 nm. Given current global environmental changes, dedicated monitoring of possible changes in cetacean distribution is necessary for adaptive conservation management. Our species distribution prediction maps can help future monitoring surveys to collect more information on understudied species. The maps can also predict suitable habitat for which observations are not yet available, followed by validation of the predicted areas by field research.

The approach we present is relatively inexpensive that parallels and is complementary to large-scale marine mammal surveys, providing a model that can be used where resources are limited. This approach can be applied anywhere to model cetacean habitat use, identify priority areas for conservation, and highlight potential areas of conflict with human activities to inform conservation management.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

Authors would like to thank to persons and institutions that provided data and contribute to this work: Yusuf Fajariyanto and The Nature Conservancy Indonesia, Sugiyanto and WWF Indonesia, Wakatobi National Park Authority and all staffs mainly who collected data in the fields, Yayasan Konservasi RASI and all volunteers, Hadi Yoga Dewanto and The Ministry of Marine Affairs and Fisheries of Indonesia for MPA data, Rokhman Khabibi for oil and gas contract area map, and Doddy Yuwono and Geospatial Information Agency of Indonesia for coral reef GIS data. Some data were obtained through data sharing agreement, therefore not publicly accessible. This work was financially supported by the Indonesia Endowment Fund for Education (LPDP) Scholarship from the Indonesian Ministry of Finance for the first author [contract number: PRJ-482/LPDP.3/2017]. The authors would like to thank the anonymous reviewers who helped to improve the quality of this manuscript.

Supplementary information

Supplementary materials of this article can be downloaded at https://doi.
org/10.1016/j.ocecoaman.2021.105555.

“It is usually a mistake to postpone action on the establishment of an MPA because biophysical information is in incomplete. There will usually be sufficient existing information to indicate whether the MPA is justified ecologically and to set reasonable boundaries.”

Graeme Kelleher

Chapter 5

Telemetry-based home range and habitat modelling reveals that the majority of areas important for pygmy blue whales are currently unprotected

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Abstract

Marine migratory species tend to be ignored in spatial planning due to the limited knowledge of their habitats and migration pathways, resulting in a disconnect between animal migration ecology and spatial management decision making. The aim of this study was to predict the migratory corridors, suitable habitats and use of marine reserves by pygmy blue whales and overlap with marine traffic. Firstly, based on available telemetry data, we analysed the home ranges, core-use areas and migratory corridors using Brownian Bridge Movement Models. Secondly, we predicted suitable habitat by modelling telemetry data against environmental predictors using Maximum entropy modelling; and lastly overlaid home ranges and suitable habitats with designated migration lanes, marine protected areas and marine traffic. Consistent movement of pygmy blue whales from Western Australia to the Banda and Molucca Seas in Indonesia demonstrated a high level of connectivity between the two regions. There is discrepancy between the designated migration lanes for large whales in Indonesian marine spatial planning and migration routes suggested by this study. The home range analysis and habitat models (all year and two seasonal models) revealed that large areas of migration corridor, core-use, and suitable habitat are currently not protected, particularly along international waters and within the Banda and Molucca Seas. The results can aid marine conservation planning by delineating important areas and areas with high marine traffic density to optimise migratory species protection.

Keywords: marine protected area, marine spatial planning, migration corridor, pygmy blue whale, species distribution model, telemetry data

5.1. Introduction

Identifying movement patterns, distribution, and habitat use of highly migratory marine species represents a vital component for their effective conservation management [15,16,219]. Conservation management including area-based management such as Marine Spatial Planning (MSP) and Marine Protected Areas (MPAs) [18,20] provides spatial protection for species from anthropogenic threats [94,95]. Our understanding of oceanic species movement is limited [368], yet it is imperative for determining the extent of habitat connectivity since species movement usually encompasses large geographical ranges, both within and beyond national waters [125], and varies depending on different species life stages [18,369]. Therefore, knowledge on species movement provides important information regarding the scale at which protective measures are necessary [369] and encourages a potential spatial framework for species conservation management across international borders and political boundaries [125].

Unfortunately, due to limited knowledge, marine migratory species tend to be overlooked in conservation management [98,124,219], and there is a disconnect between animal movement science and conservation policy and decision-making [370,371]. Use areas of migratory species such as marine mammals are often poorly defined and receive little or no protection, since marine reserve establishment tends to focus mainly on sessile coastal species or species with limited mobility [109]. A key issue for the conservation of migratory species is the identification of important habitats throughout the annual cycle, including 'core-use areas' where individuals spend a lot of time and 'corridors' used during migration.

Information on cetacean species around Indonesia was primarily based on whaling operations [78,192], strandings [193,194], and incidental sightings [77]. Only recently have cetacean monitoring programs been conducted at several sites in Indonesia [37,55,195]. Recent cetacean records are mainly collected by coastal boat surveys, particularly with platform of opportunity or incidental observations [196], as well as limited-coverage aerial surveys, while telemetry data is lacking. Achieving a more detailed understanding of cetacean movement has been difficult, because they are elusive species, highly mobile and spend relatively little time at the surface [188,189]. Boat and aerial surveys are limited to areas and seasons where the surveys occur [26,227], meaning data on movements across the ocean basin and in remote areas are limited. Alternatively, telemetry data provides movement data on individual animals [27,223] that spend most of their lives away from direct observation [222], since tags record the information wherever the animal moves [15] with reasonable resolution and accuracy [24,123]. Telemetry data enables unprecedented insights into species movements, habitat characteristics, critical habitats, the range of uncommon or endangered species, behaviours, better population size estimates and the interconnectedness of subpopulations [15,372]. The information is crucial for conservation applications, to informing management policy [371,373], assessing functional MPA boundaries [107] and supporting the recovery of endangered cetacean populations [220].

A satellite tagging study of a marine migrant, the pygmy blue whale (*Balaenoptera musculus brevicauda*, hereafter PBW), which pass Indonesian waters, has recently been conducted [76]. The study revealed basin-scale oceanic migrations and full latitude range of the Indian Ocean from West Australia to the Banda and Molucca Seas, Indonesia [76]. Double et al. [76] acquired many telemetry records, although the data have not yet been used for home range analysis and habitat modelling, and so the study does not fully capture the potential for improved knowledge on PBW ecology. The core-use areas and migration routes used, seasonal distribution patterns and environmental variables determining the species distribution remain virtually unknown.

PBW is one of the least known whale species, and in the early 1960s the PBW was recognised as a subspecies separated from Antarctic blue whales [374–376]. The whales were commercially exploited in the 20th century and their status is currently listed as 'Data Deficient' in the IUCN Red List of Threatened Species [377]. The number of individuals reduced from a possible 12,000–13,000 animals in the pre-whaling era to very low levels during the whaling era, before increasing again due to the whaling moratorium (~4,000 animals in the early 1970s), although the current population is still unknown [378]. Their original abundance was probably lower than that of Antarctic blue whales, but is likely less depleted at present [193].

The general movement patterns for PBW have only recently been elucidated from satellite tagging [76] and follow the perceived migration patterns of baleen whales. The seasonal movement patterns are traditionally thought to occur from productive high-latitude cold feeding areas in summer to oligotrophic, tropical or sub-tropical warm calving and mating areas in the winter [228,379]. However, season-specific estimates of individual movements, their resultant distributions and migration corridor width do not exist. Large variation in migratory patterns has been reported for baleen whales, and for some populations virtually no information exists on migratory pathways and destinations [25]. Since the whales pass through many areas, their exposure risk is higher, mainly from human activities such as hydrocarbon exploration and oil/gas infrastructure [380], shipping traffic [381], fisheries [382,383], and pollution [51].

To adequately conserve whales, including PBW, entire migration routes should be protected. Indonesian regulations mandate incorporating marine biota migration routes as lanes in provincial MSP establishment and their critical habitats in MPA designation [230,308]. However, hitherto there is no scientifically accepted method in determining the lanes. The representation of the species distribution and movement in management areas is not well known and their efficiency in providing proper habitat protection needs to be evaluated. This study, therefore, elucidates how to better perform lane allocation in an MSP and the zoning system design of an MPA.

Next, spatial assessments are necessary to evaluate whether species critical habitats are already protected by the managed areas (MSP and MPAs) [107]. MPAs that overlap with the range of the large whales are never specifically established to protect the migrating species, but rather to protect a range of bioregions, ecosystems, habitats, other species, and socioeconomic interests (e.g., Savu Sea in Indonesia [308,384]). Still, assessing the extent of coverage offered by these reserves is important to unveil the extent of the overlap. Until now, the use of MPAs in Indonesia by migratory species has not been studied, which makes it unclear how much of their important seasonal habitats are protected, as these habitats have never been identified.

In order to analyse the role of current MSP and MPAs for pygmy blue whales, the extent of the whale migration corridors and their spatial distribution must be determined. Home range models and species distribution models (HRM and SDM) serve this aim and telemetry data are increasingly being used in HRM and SDM [181,227]. HRM can be used to delineate species expected movement trajectories and migration corridors [95,227,385], whilst SDM can predict suitable habitats of focal species based on statistical relationships between recorded occurrences and environmental predictor variables [181,192,227,386]. The information gained from both types of models can give ecological insights [15,387] as well as support conservation and management planning [27,181,227].

This study aimed to assess the relevance of current MPAs for pygmy blue whale protection by identifying their overlap with home ranges and suitable habitats of pygmy blue whales. Home ranges include migratory corridors, routes and core-use areas of species individuals and suitable habitats will be identified using available telemetry data. Our results can be used to guide conservation and management planning efforts for pygmy blue whales in Indonesia and can serve as a model for assessing the representativeness of protected areas for whales in other parts of the world where telemetry data are available.

5.2. Materials and Methods

5.2.1. Study area

The study area ranges from Western Australia to East Indonesian waters from 1° N - 36° S and 109-132° E (Fig. 5.1). The area has a diverse and complex submerged topography; a wide continental shelf extends from the Australian shorelines with deep waters occurring far offshore; in contrast, a narrower continental shelf is found in East Indonesia with water depth increasing abruptly from the shelf edge relatively close to the shoreline. Inter-island channels in Indonesia and continental shelves in Australia serve as passages for migrating marine mammals [76]. The Indonesian waters are situated in an upwelling system, where wind regimes and oceanic currents strongly influence the temperature and primary productivity [73,74]. The Perth Canyon in Western Australia is an area with high productivity, since it is located within the subtropical frontal zone [388] with complex submerged topographic and unique circulation features [389]. In the Ningaloo Reef in the North West Cape, primary production is also relatively high and this is similar to the productivity in the upwelling regions [390].

5.2.2. Telemetry data

Satellite tracking data were obtained from a previously published study for eleven pygmy blue whales that were tagged in the Perth Canyon, Australia in 2009 and 2011 (Supplementary Table S1) [76]. Instead of using only the locations representing the highest accuracy i.e., Argos locations with Location Class (LC [391]) 2 and 3, we decided to use all available LCs (in descending order of accuracy: 3, 2, 1, 0, A, B). We did not use LC Z because Argos indicated that it is invalid. Some studies have recommended to use LC 0, A and B in addition to LC 1–3 [391,392], especially when the number of locations is limited as in this study. Studies using only low numbers (n <10) of tagged animals have been done previously [25,182,223]. An algorithm developed by Freitas et al. [393] based on swimming speed, distance between successive locations and turning angles was used for location filtering. Tracks were then reconstructed using these filtered locations. For further information on tagging methodology and data filtering see Double et al. [76].

Our focus was the migration of the whales from Australia to Indonesia. Thus, a set of positions (n=95) from one individual (tag 98135) in southern Australia was excluded, since it did not migrate in that direction. The tag of this individual whale previously experienced a three month signal pause in which locations were not transmitted from the last reported location in the Banda Sea, Indonesia [76].

5.2.3. Home range analysis

Home ranges in wildlife studies describe the geographically restricted area used by animals, and this is done by estimating a probability density function that describes the likelihood of an animal being present in a given area [24,127]. Several home range methods are available, and careful consideration is needed before applying a method [131], since unjustified conclusions can have big impacts on species management. Traditional kernels do not incorporate information on the order of recorded locations or elapsed time between these locations, which are crucial to assess the movement between habitats [394]. The traditional kernels simply estimate point density and therefore perform very poorly for assessing the migration routes of animals [116,129].

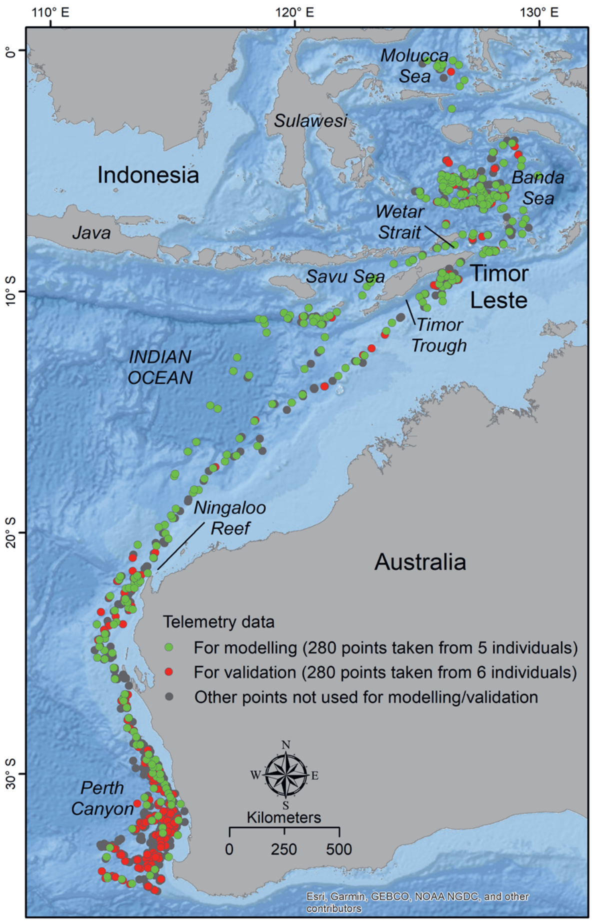


Fig. 5.1. Pygmy blue whale telemetry study area ranging from the western Australian to the eastern Indonesian waters. The different colours of the telemetry data points indicate how these are used in the habitat modelling.

We used a Brownian Bridge Movement Model (BBMM) because it is a more advanced kernel method that takes into account: (i) the level of uncertainty of the recorded locations, (ii) the trajectory in between reported locations, and (iii) minimises temporal and spatial autocorrelation of the tracking data [129]. The BBMM assumes that the area between consecutive positions is part of the 'home range' and that the degree to which this in-between area is used is related to the amount of time spent traveling between 2 points, in relation to the speed of the animal. This reduces the dependence on each individual location and provides a more accurate representation of the used space [227]. The BBMM is a conditional random-walk (i.e., stochastic) model where the start and end (of the bridge) are relatively accurate (known) locations and the variance in intermediate location estimates is the largest mid-point of the bridge [95]. Therefore, it explicitly addresses the problem of connections (i.e., bridges) in predicting trajectories of movement between successive locations [395].

The BBMM requires the sequence of time-specific location data, the estimated error associated with the location data, and grid-cell size for the output [129]. The error of locations was assigned by the Argos system [391,392], and for our dataset it ranges between 0.25 and >1.5 km [76]. We chose 2.5 km for the error value, which was a reasonable estimate for our Argos dataset, and a cell size of 10 km, as a compromise of desired spatial resolution and computing time. Changing the error in a variable value and decreasing the cell size greatly increases the computing time. The migration routes estimated by the BBMM are unique in that they reflect two metrics of migratory behaviour: time spent in an area and movement rate. Different probabilities were applied to get the core-use areas (where animals spend a lot of time during migration and move slowly) and migration corridors (i.e., the possible space used during migration where animals spend the least time and move quickly). We used 90% probability for migration corridors (higher probabilities can include more extraneous or transitory locations [396]); and 50% probability for core-use areas. Home ranges were assessed per individual and were combined by overlaying the areas for each probability and count the number of individuals per area. From these arrangements the overall merged home ranges based on migration corridors and core-use areas were constructed representing population-level space use [395,397]. We used bathymetry (0 m depth) as a mask to prevent home ranges being estimated over land. BBMMs were calculated in R package using the 'brownian.bridge' function (https://www.rdocumentation.org/packages/BBMM/versions/3.0/topics/brownian.bridge).

For home range analysis, data from all eleven animals was used, except the data subset that was excluded in Section 5.2.2. We used all individual tracks, including those of incomplete migrations (e.g., whales that only occur around West Australia), because we deem all trajectories to contribute important information about the migration ecology of the species.

5.2.4. Habitat suitability modelling

To assess pygmy blue whale habitat preference and spatial distribution as well as to investigate the influence of environmental predictors on the species distribution patterns, a habitat suitability model, the maximum entropy model (Maxent), was applied. Maxent was well adapted to satellite telemetry data and has recently been successfully applied for modelling cetacean species distribution [192,269,386,398–400].

Maxent is a machine-learning technique that can reconstruct non-linear, complex interactions between the presence data and a set of environmental predictors [178]. The basic principle of the Maxent model is to compare environmental predictors at the positions where animals have been observed in contrast to the environmental predictors at a random selection of positions in the background environmental conditions [178]. Maxent is a powerful predictive modelling method when there are presence-only data and no absence data [166], with small and unbalanced sample sizes [178], and when data are prone to positioning errors [401], all of which is often true for satellite telemetry data. Maxent coupled with proper data sub-sampling in cases where a small number of individuals have been tracked [269] makes it a forceful tool for the investigation of species-habitat relationships.

The following Maxent settings were chosen for our data characteristics and the specific questions of the study [318]. First, logistic output was selected to easily understand where the model predicts the occurrence of the species. Second, 70% of the data was used as training data and 30% as test data. Third, regularisation parameters were set as default to avoid model overfitting; auto feature class types and 500 maximum iterations were also set as default. Fourth, a setting that allows replacement in sampling replicates (i.e., 10-fold bootstrap replicated run type) was selected, which is particularly useful when the sample size is small [319]. Lastly, the maximum number of background points was set to 10,000 (over 12,261,601 available grids) to be sure that the environmental conditions in the area were met, as the number of background points >10,000 does not improve the predictive ability of the model [271]. We performed the habitat modelling using Maxent software version 3.4.1 (https://biodiversityinformatics.amnh.org/open_source/maxent). Maxent created response curves for each environmental predictor and computed the percent permutation importance of the predictors to the model in a jack-knife cross-evaluation procedure [166]. This procedure quantifies firstly the gain when the variable is the only variable in the model, and secondly the decrease in the gain if the variable is omitted from the full model.

To distinguish suitable and unsuitable habitats, we applied the ‘10th percentile training presence threshold’ to the predicted distribution maps in ArcGIS 10.6.1. This threshold was chosen because it has been shown to be the best threshold when true absence data are not available [272]. It then selects values above which 90% of the training presence is correctly classified, thus giving more conservative prediction estimates [273]. The mean threshold of 10 replicates of the Maxent model output was used as a binary threshold for presence/absence of PBW, above which a suitable habitat is considered to occur.

For the Maxent modelling, only data from five individuals was used (Supplementary Table S1), since these whales performed migration all the way to Indonesia. One exception was tag 98141, which paused transmission from the time of deployment in the Perth Canyon and only restarted transmission in the Molucca Sea in June-July. Because this animal reached Indonesian waters, we included this track in modelling. The tracking data from the other 6 individuals (Supplementary Table S1) was used for external validation, subsampled to be proportional with the number of locations used in the Maxent model. The telemetry data per individual is sequentially correlated, therefore we used the following steps for sampling the whales' positions with the aim of reducing spatio-temporal autocorrelation. Firstly, we removed all positions from the first 2 days after tagging to further reduce the spatial and temporal influence of the release site [269]. Secondly, only one position (the best location class) per animal per day was selected manually [398]. Lastly, we rarefied the positions by excluding positions that were located <10 km apart using SDMtoolbox [316]. These steps reduced the number of location data points from the original 1378 locations to 280 locations.

Most baleen species undertake large seasonal migrations [25,220,402–404], therefore under the assumption they would express different habitat preferences during different times of the year, we split the telemetry data into seasonal strata. We explored different models i.e., 'all year' model (n=280 locations) and two separate seasonal models: Inter-monsoonal/Transition 1 season (T1 season, March-May, n=140 locations) coinciding with the Austral autumn, and SE monsoon season (June-August, n=140 locations) coinciding with the Austral winter. Because our focus was on the broad-scale habitat use of PBW, we decided not to run separate models by individual whale, but rather to run one model for all individuals. Results provided information on the population-level habitat associations for the whales.

Eleven submerged topographic predictors and three oceanographic predictors were initially prepared based on the expected ecological relevance to PBW habitats in the study area (Supplementary Table S2). The rationale of the selected predictors, sources and derivation process of the predictors are given in Supplementary Table S2. Prior to modelling, we checked the multi-collinearity among candidate predictors which could potentially overshadow the effect of a particular predictor. Only predictors with Spearman's correlation values ≤0.7 were used in habitat modelling (Supplementary Table S2). Four predictors were finally selected for 'all year' and T1 season models, i.e., slope, distance to -1,000 m isobaths, distance to shelf, and sea surface temperature. The same predictors, and in addition the chlorophyll-a concentration (Chl-a), were selected for the SE monsoon model.

The performance of habitat models are commonly assessed by the Area Under Curve (AUC) of the receiver-operating-characteristics (ROC) [166]. AUC evaluates how well the model predictions discriminate between locations where observations are present and absent [319]. As there are no true absence data, AUC scores represent the probability that a randomly chosen presence location was more likely to have the species present than a randomly selected pseudo-absence location chosen from the entire study area [166]. In this study, the model performance assessment is performed using (i) training data, (ii) internal validation data or test data, and (iii) external validation data. An AUC value >0.5 indicates that the model performs better than random [178,271], and a good model will have an AUC value >0.75 [276]. An AUC of 0.75 means that in places where a species is present in 75% of the cases, the predicted values will be higher than where the species has not been recorded. To overcome overfitting of models, the AUC values of training and test data should be comparable [405].

We also applied three additional model evaluation metrics: True Skill Statistic (TSS) [277], sensitivity (the proportion of observed presences correctly predicted by the model), and specificity (the proportion of observed absences or pseudo-absences correctly predicted by the model) [275]. TSS is 'sensitivity + specificity - 1' and in this manner it corrects for the accuracy by chance and is not dependent on prevalence [277]. A TSS value >0.4 is moderate and >0.6 is good to excellent [278,279]. A model with a sensitivity value >0.7 is a good model as well [280]. A good model will have a higher sensitivity than its specificity [112]. We used several model evaluation metrics because none are perfect when true absence data is not available.

5.2.5. Overlap of areas important for PBWs with marine reserve use, designated migration lanes and shipping traffic

To evaluate the use of existing MPAs by PBWs, we calculated the areas (size and proportion) used by the whales (i.e., home range [including migration corridors and core-use areas from BBMM], and suitable habitats from Maxent, together as areas important for PBW) that fell within existing MPAs versus unprotected areas. The area calculation was performed in ArcGIS 10.6.1. Boundary data of MPAs in Indonesia were obtained from the Ministry of Marine Affairs and Fisheries, while the data for Australia were downloaded from the UNEP-WCMC website (https://www.protectedplanet.net/country/AU). To assess the suitability of designated migration lanes for large whales within Indonesian MSP and potential conflict with marine traffic, we overlaid the lanes with the migration corridors from the BBMM and shipping density. The discrepancies between both spatial functions were then investigated. The designated migration lane map encompassing the Savu, Flores and Banda Seas was obtained from the Authority of National Aquatic Conservation Areas (BKKPN) Kupang, Indonesia. Shipping density data were obtained from a global map of shipping traffic [324].

5.3. Results

5.3.1. Analysis of movement patterns of pygmy blue whales

In order to better understand movement patterns of PBWs, we provided quantitative information on spatial extent of movement, dispersion and connectivity. Most individuals in Australian waters at the Perth Canyon migrated northward within relatively close proximity (within 100 km) of each other (Figs. 5.1 and 5.2). However, from the Ningaloo Reef onwards, individual whales dispersed over a wider distance (>500 km apart) from each other, especially in the Indian Ocean international waters.

Whales used two different routes, namely: through the Savu Sea or the Timor Trough as shown by whale 88739 and whale 98135 respectively.

Spatio-temporal information on PBWs in the whole study area also included areas that are rarely or never surveyed, such as international waters in the Indian Ocean and the middle of the Banda Sea. The tagged whales showed relatively high residency in the Banda Sea, which they occupied for >3 months through the SE monsoon season, coinciding with Austral winter. One individual even dispersed to the Molucca Sea. Interestingly, PBWs followed nearly similar migration paths within and between years, mainly along the Western Australian coastline, reflecting a fidelity of migratory paths.

5.3.2. Home ranges (migration corridors and core-use areas)

Migratory corridors and core-use areas between the Western Australia and Indonesian waters were clearly identifiable from the BBMM home range analysis (Fig. 5.2). The individual home ranges varied greatly (4-fold) in size, as did core-use areas (40-fold) (Table 5.1). In addition, the shape of home ranges was highly variable among individuals, and differed in degree of overlap (Fig. 5.2a,b). The overlapping individual home ranges represent areas that were used by several individuals during migration. Ten out of eleven whales had overlapping home ranges (Fig. 5.2a) and eight whales had overlapping core-use areas (Fig. 5.2b), both mainly around the Western Australian continental shelf.

The combined home ranges of the eleven whales covered most of the Australian EEZ, all Timor Leste EEZ, and a part of the east Indonesian waters (Fig. 5.2a,c). The combined home ranges (BBMM 90%) that also function as migratory corridors comprised ~2.2 million km^2 (Table 5.2). The core-use areas (BBMM 50%) of all combined individuals consist of five smaller aggregation areas located in the Western Australian waters, three localised areas in Indian Ocean international waters (counted as 1), and the Timor Trough, Banda Sea, and Molucca Sea (Fig. 5.2b). The combined core-use areas comprise ~0.8 million km^2 (Table 5.2), accounting for 36.6% of the total home ranges.

5.3.3. Habitat suitability models

The predicted spatial distribution of PBWs for 'all year' and two seasonal models were visually dissimilar, indicating clear seasonal movement patterns (Fig. 5.3). The distribution in the 'all year' model aligned quite well with telemetry data, except for a small part in the Perth Canyon and Indian Ocean (Fig. 5.3a). The 'all year' model also predicted highly suitable habitats in areas where telemetry data were not recorded, such as in the southern Java and southern Sulawesi Seas (Fig. 5.3a).

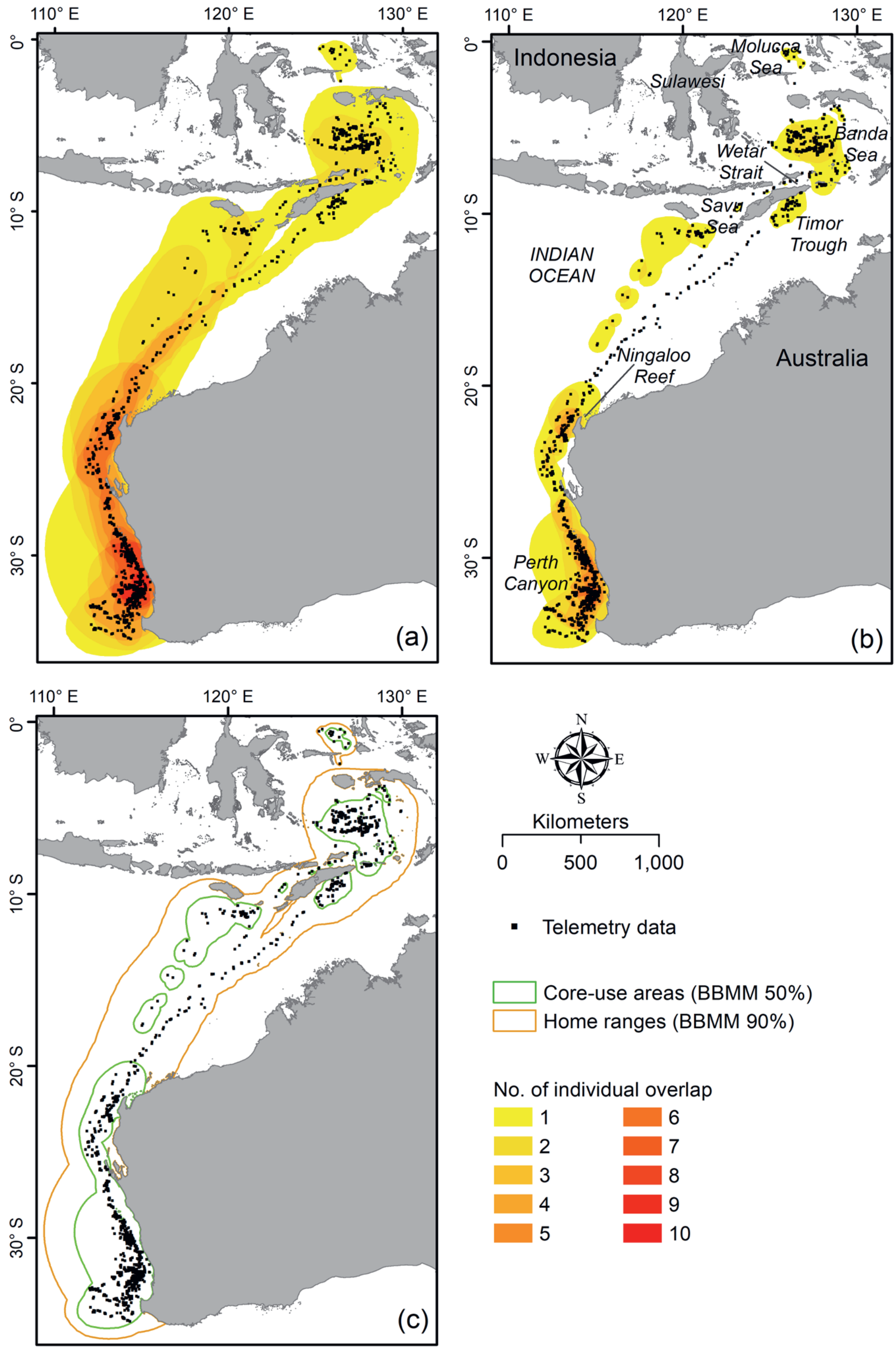


Fig. 5.2. The number of overlapping areas of individual whales in (a) home ranges (including migration corridors) and (b) core-use areas indicated by gradual colours from yellow to red. The combined home ranges (c) (Brownian Bridge Movement Model-BBMM 90% isopleths, orange polygons) and core-use areas (BBMM 50% isopleths; green polygons) of 11 satellite-tracked pygmy blue whales in the study area.

Chapter 5

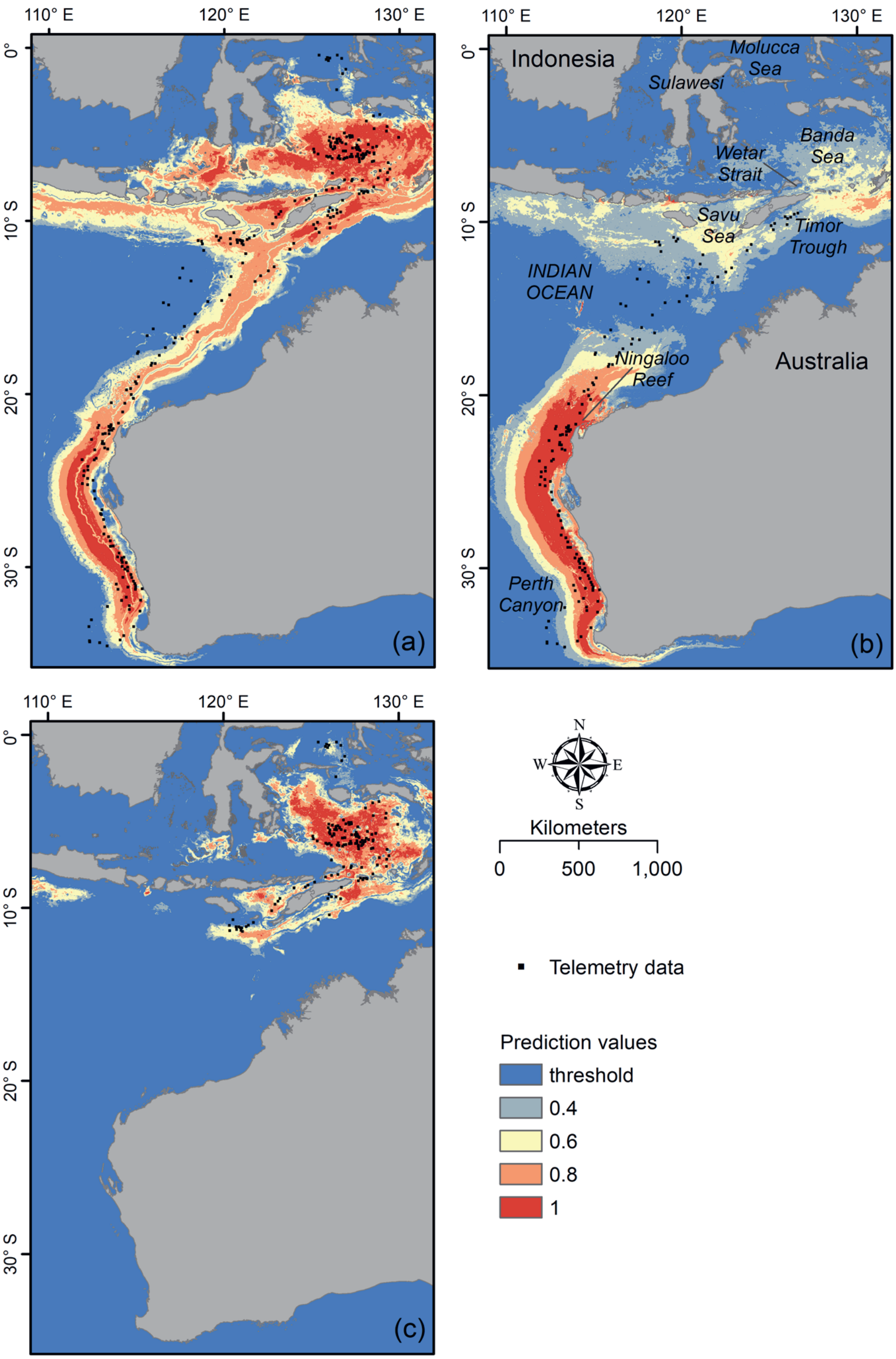


Fig. 5.3. Pygmy blue whale distributions as predicted by Maxent modelling for (a) all year and per season: (b) T1 - Transition 1 season (March-May) and (c) SE - Southeast monsoon season (June-August). The value of the predictions is classified into five classes ranging between 0 and 1. The 10th percentile training presence threshold indicates unsuitable habitats (dark blue areas).

Table 5.1. Area (km²) of individual pygmy blue whale home ranges (migration corridors, core-use areas)

No.	Tag ID	Area of individual home range (km²) Migration corridors (BBMM 90%)	Core-use areas (BBMM 50%)
1	53734	77,385	16,394
2	53791	627,523	248,358
3	88731	35,756	8,948
4	88739	623,759	131,126
5	88740	99,380	31,577
6	98106	755,396	318,291
7	98108	1,286,448	328,466
8	98115	180,083	43,085
9	98134	244,392	76,997
10	98135	964,815	188,238
11	98141	39,143	11,317
	Mean	448,553	127,527
	SE	129,226	37,401
	Max	1,286,448	328,466
	Min	35,756	8,948

*BBMM - Brownian Bridge Movement Model.

Table 5.2. Overlapping area (km²) and proportion (%) between home ranges (migration corridors & core-use areas) and Maxent-predicted suitable habitats against marine protected areas (MPAs)

	Home ranges (BBMM) Migration corridors (90%)	Core-use areas (50%)	Suitable habitats (Maxent)
Within MPAs:	**430,521 km² (19.3%):**	**151,124 km² (18.6%):**	**294,742 (12.9%):**
- Indonesia	37,703 km² (1.7%)	3,921 km² (0.5%)	59,889 km² (2.6%)
- Australia	391,860 km² (17.6%)	147,177 km² (18.1%)	234,008 km² (10.3%)
- Timor Leste	958 km² (<0.01%)	26 km² (<0.01%)	845 km² (<0.01%)
Outside MPAs*:	**1,797,203 km² (80.7%):**	**663,143 km² (81.4%):**	**1,983,942 km² (87.1%):**
- Indonesia	790,047 km² (35.5%)	272,692 km² (33.5%)	1,366,995 km² (60.0%)
- Australia	714,353 km² (32.1%)	332,290 km² (40.8%)	557,651 km² (24.5%)
- Timor Leste	75,076 km² (3.4%)	26,190 km² (3.2%)	57,760 km² (2.5%)
- International	217,732 km² (9.8%)	31,972 km² (3.9%)	1,536 km² (0.1%)
Total	**2,227,725 km² (100%)**	**814,267 km² (100%)**	**2,278,684 km² (100%)**

*Areas outside MPAs are areas that fall within the EEZ waters of each country and international waters. The International waters are high seas beyond EEZ boundaries. The EEZ boundaries were obtained from the VLIZ Maritime Boundaries Geodatabase [406]; some boundaries are disputed. Abbreviations: MPAs - Marine Protected Areas; BBMM - Brownian Bridge Movement Model.

The seasonal shift in telemetry records to the north was also reflected in the seasonal model outputs. During the T1 season, a strong presence of PBWs was predicted in the Western Australian waters (Fig. 5.3b). In the Indian Ocean, an absence of distribution was predicted between Australia and Indonesia, while telemetry records still occurred there (Fig. 5.3b), bordered by a narrow distribution with moderate predicted values in the south of Indonesian islands. During the SE monsoon, the predicted whale distribution was concentrated in Indonesian waters, mainly in the Banda Sea, which aligned well with the telemetry presence data (Fig. 5.3c).

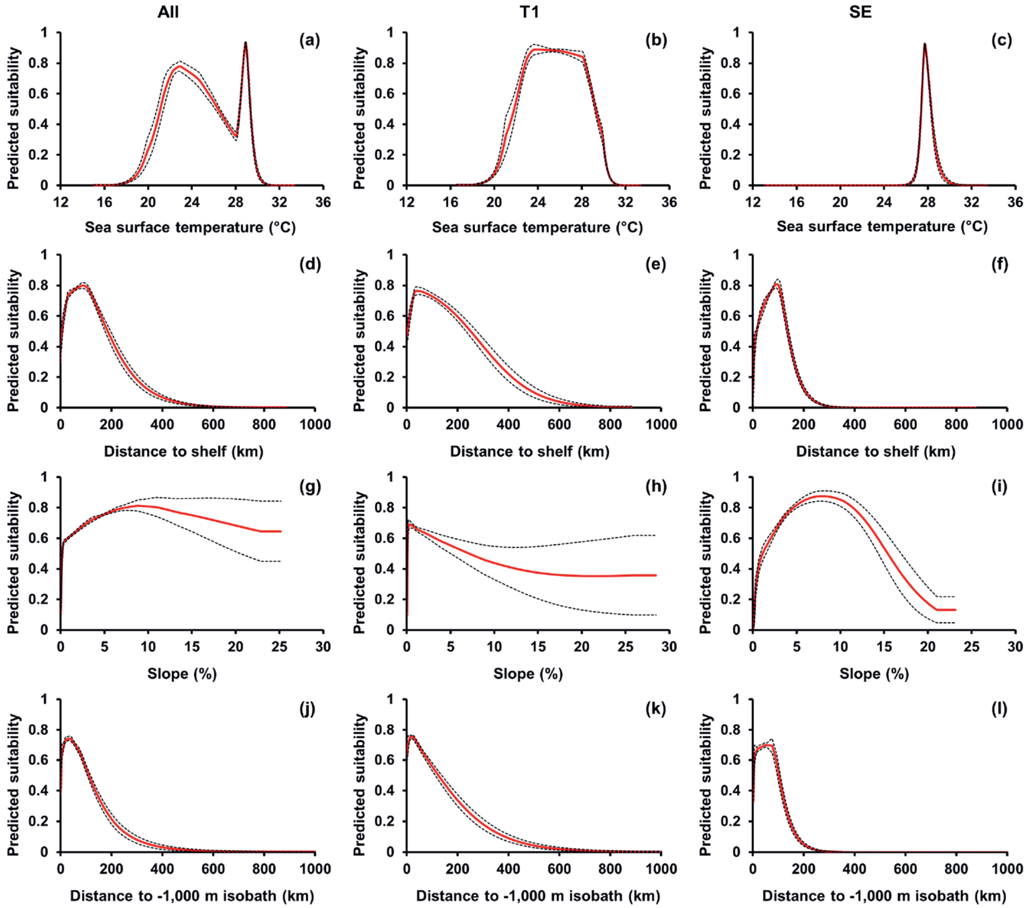
The performance metrics of the Maxent modelling generated using both internal and external validation data (Table 5.3) indicate good predictive power and model robustness with AUC and sensitivity values >0.75 and TSS values >0.4. Model sensitivity for 'all year' and two seasons was higher than its model specificity (Table 5.3), indicating that the model performed well in predicting where whales occurred [112].

Table 5.3. Maxent model performance metrics (mean ± SD)

Seasons	Metrics	Internal validation (test data)	External validation
All	AUC	0.853 ± 0.015	0.832 ± 0.039
	TSS	0.506 ± 0.039	0.473 ± 0.097
	Sensitivity	0.877 ± 0.037	0.899 ± 0.001
	Specificity	0.628 ± 0.024	0.574 ± 0.097
T1	AUC	0.881 ± 0.013	0.902 ± 0.038
	TSS	0.484 ± 0.054	0.583 ± 0.163
	Sensitivity	0.848 ± 0.096	0.900 ± 0.001
	Specificity	0.637 ± 0.069	0.683 ± 0.163
SE	AUC	0.953 ± 0.006	0.951 ± 0.010
	TSS	0.720 ± 0.050	0.779 ± 0.037
	Sensitivity	0.874 ± 0.017	0.900 ± 0.001
	Specificity	0.845 ± 0.058	0.879 ± 0.037

Abbreviations: All - all year, T1 - Transition 1 season (March–May); SE - Southeast monsoon season (June–August), AUC - Area Under Curve of receiver-operating-characteristic, TSS - true skill statistics.

Sea surface temperature (SST) and distance to shelf were the most important predictors in determining environmental niches for the PBWs in all model outputs, with a permutation importance of >0.457 and >0.227 respectively (Fig. 5.4). Slope (0.130) and Chl-a (0.107) were subsequently also the next important predictors for the 'all year' model and SE model (Fig. 5.4). The shape of the response curves of SST and slope in all models was different, while that of the distance to shelf and distance to the -1,000 m isobath was generally similar (Fig. 5.4). The 95% confidence intervals in the response curves based on the 10 bootstrapped replicates are narrow (less vary among replicates) for all predictors except slope.



Predictors	Permutation importance		
	All	T1	SE
Sea surface temperature	**0.457**	**0.536**	**0.574**
Distance to shelf	**0.296**	**0.283**	**0.227**
Slope	0.130	0.096	0.071
Distance to -1,000 m isobath	0.117	0.085	0.021
Chlorophyll-a concentration	n.a.	n.a.	0.107

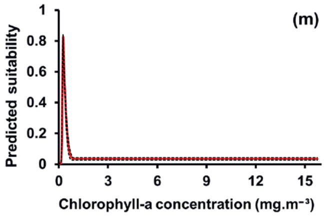


Fig. 5.4. Response curves of the predicted suitability of pygmy blue whale habitats across the range of values for different environmental predictors. Red lines represent the mean response curve from 10 bootstrapped Maxent model replicates, while the dashed black lines represent 95% confidence intervals. Different response curves are presented for all year model (All, left panels) and per season: T1 - Transition 1 season (March-May; middle panels) and SE - Southeast monsoon season (June-August; right panels). The table presents the relative importance of each predictor in Maxent model outputs. In bold the two most important predictors that determine pygmy blue whale habitats. The relative importance value is rescaled to sum 1. n.a. - not available.

The predicted suitability of PBW habitats increased with low SST (~25°C) in the T1 season, and with higher SST (~28°C) in the SE monsoon season (Fig. 5.4b,c); this is reflected in the 'all year' model (Fig. 5.4a) as a bimodal distribution with a low (23°C) and high (29°C) SST. In the 'all year' and SE models, the predicted habitat suitability increased with an increasing distance to a shelf (~100 km), while for the T1 model a closer distance of only ~30 km was found (Fig. 5.4d-f). For both the 'all year' and SE models, the optimal slope reaches ~10% which relates to the complex deep seafloor. However, it was close to ~1% in the T1 model which relates to the gentle undulating continental shelf (Fig. 5.4g-i). In the 'all year' and two seasonal models, the predicted suitability was negatively associated with distance to the -1,000 m isobath, with high predicted whale occurrence closer to this feature at a distance of ~30 km (Fig. 5.4j-l). Finally, for the SE model the high predicted suitability occurred in offshore waters with low Chl-a (~0.3 mg m^{-3}), although most of the Chl-a at the study area was in fact low, and the few very high Chl-a areas only occurring near coastlines that were unfavoured by the whales.

5.3.4. Overlap with MPAs, designated migration lanes, and marine traffic

The home range analysis and habitat modelling maps were compared with MPA maps to examine the proportion of important areas that actually fall within the boundaries of MPAs. Overall, only <20% of the PBW's migration corridors and core-use areas, and <13% of the suitable habitats identified in this study are currently protected in MPAs, mainly in Australia (Table 5.2, Fig. 5.5a). Further, none of the migration corridors, core-use areas, and suitable habitats in international waters were located within MPAs. The majority (>80%) of migration corridors and core-use areas are currently not protected by existing MPAs, mainly in Australia (~40%) and Indonesia (~35%). A large area (60%) of suitable habitats within the Indonesian waters, mainly in the Banda Sea and southern Java, is likewise unprotected by existing MPAs. Moreover, almost 10% of the migration corridors are in international waters beyond national jurisdiction.

The designated migration lanes for large whales in Indonesian marine spatial planning (MSP) slightly deviate from migration routes found in this study, revealing that they do not match for PBW (Fig. 5.5b,c). For instance, the migration routes in the Wetar Strait, Timor Trough and Molucca Sea are not currently included in the designated migration lanes in Indonesia, although migration corridors occurred there (Fig. 5.5b,c; purple circles). The home ranges, core-use areas, suitable habitats, migration routes and designated migration lanes also overlap with some of the busiest shipping routes (>60 routes/km^2/yr) in the region (Fig. 5.5b,c).

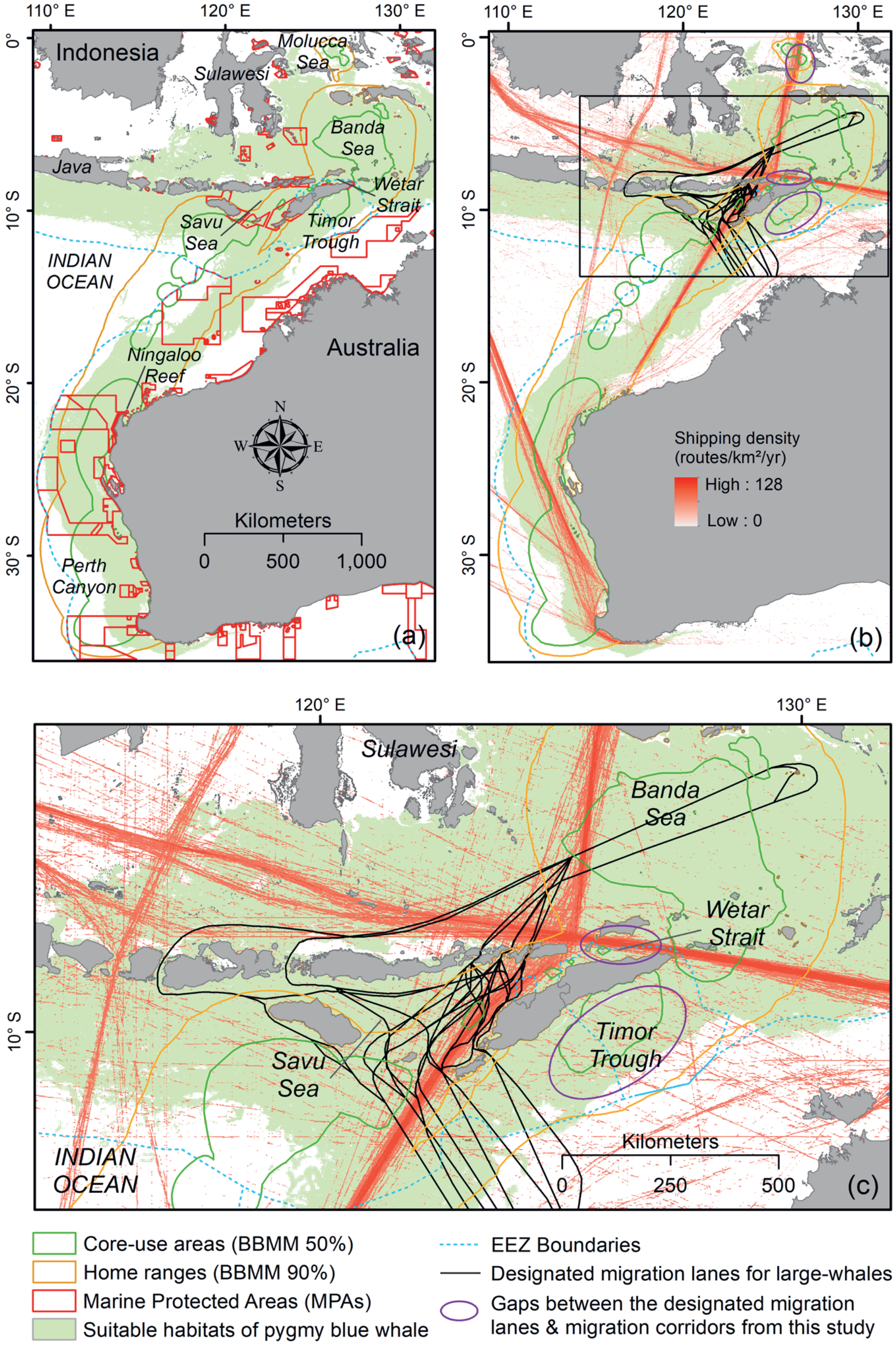


Fig. 5.5. The areal overlaps between home ranges (migration corridors), core-use areas and Maxent-predicted suitable habitats against: (a) marine protected areas (MPAs), and (b) designated migration lanes for large-whales in Indonesia, and marine traffic. Panel (c) is the zoom-in area of the black box in the panel (b). The exclusive economic zone (EEZ) boundaries were obtained from the VLIZ Maritime Boundaries Geodatabase [406]; some boundaries are disputed. Purple circles indicate important unprotected PBW migration routes.

5.4. Discussion

The current knowledge on movement patterns, distribution and habitat use of marine migrants is very limited, yet crucial for effective conservation management. In this study, we have successfully demonstrated the utility of telemetry data in identifying migration corridor width, home range and potentially suitable habitat for pygmy blue whale (PBW) migrating from Western Australia to east Indonesian waters. Using both home range and habitat modelling approaches, we unveiled that much of the PBW habitats across the study area were outside of the marine reserve systems. Here we first evaluate the limitations and technical aspect of using telemetry data for home range and habitat modelling. Then, we discuss the PBW home ranges and habitats as well as their overlap with conservation areas, designated migration lanes and potential conflicts with marine traffic to optimise protecting the whale habitats.

5.4.1. Caveats and quality of the models

In this study, eleven individual PBWs are used and home ranges of two individual whales were estimated from datasets that had <20 locations, although we had a mean of 116 locations per animal (±SE 38). While the knowledge of species movements increases with the sample size of tracked animals, relatively small sample sizes (e.g., <10 individuals) can still be sufficient to provide important information for conservation actions, as has been shown before [25,124,182,223].

Although telemetry data typically concerns a limited number of samples over short time periods [224,225], tracking one individual can reveal the movement in hitherto unknown areas, tracking several individuals can indicate individual variability, while tracking >30 individuals can reveal populations behaviour [407]. The high cost restricts the number of tags deployed [221], while observation errors inherent to most tracking technologies [408], especially light-based geolocation [20], limit the ability to make strong inferences at the population level. Also, telemetry mostly describes specific life history stages of the species that may have specific habitat use [98,222].

For habitat suitability modelling, a statistical challenge is that telemetry provides serially correlated presence-only observations of a limited number of animals that display a complex spatial behaviour in relation to their environment [408,409]. The non-normal measurement errors in the data [410] add to the challenges of inferring habitat preference at a population level [408] due to geographical, temporal or individual biases. For the analysis of habitat use, covariates are required in addition to telemetry data [98]. Modern statistical models such as Maxent offer approaches to minimise these limitations, for example by reconstructing complex interactions between the presence data and a set of environmental predictors [178]. Maxent is a forceful method when there are presence-only data and no absence data [166], with small and unbalanced sample sizes [178], and when data are prone to positioning errors [401], all of which are characteristics of telemetry data. Some studies used telemetry data to construct as well as validate the model, which can bias estimates of model performance [411,412]. In the current study, we used an independent dataset, as we consider this crucial, especially for models that support management decision making [112].

The model evaluation metrics (AUC, TSS, sensitivity and specificity) indicated that, overall, Maxent predicted the PBW distribution mostly with moderate to high discrimination power. The standard deviation of the average of evaluation metrics was mostly small (<0.05) indicating a consistent and reliable model output, and appropriate robustness [276,279]. The model sensitivity for each of the three seasonal model outputs (all year, T1 and SE) was higher than the model specificity (Table 5.3), indicating that the models performed well in predicting whale occurrences [112]. The importance of each environmental predictor for PBW distribution in the model was evaluated by creating response curves (Fig. 5.4).

Given the limited number of tagged whales, our results can only be applied to the period of data collection which implies that additional data may refine the future predictions. Without true absence data in this study, pseudo-absences were used, and (hard to collect) true absence locations would enhance the model output [166]. Still, the Maxent model predicted known PBW suitable habitats in seasonal agreement with telemetry data, highlighting the ability of the model to predict PBW habitat preference. Comparison between suitable habitats from Maxent and BBMM home range analysis delivered a considerable match, strengthening its value in supporting conservation management. Our comprehension of species migratory patterns and their spatial connectivity in the world's oceans is limited and yet important for conservation [413]. For instance, the online database of species distribution maps such as AquaMap [311] lack the spatio-temporal information on migration pathways and spatial connectivity required to realise a more specific area-based management [125]. Even considering the abovementioned limitations, telemetry data provides valuable information on animal movement ecology for areas or species with limited or no precedent investigation [219,220]. Our study unveiled PBW movement patterns from the Western Australia to east Indonesia and highlights the connectivity between the two regions. The migrations across large distances, confirming the connectivity between populations at oceanic basin scales, were documented in other whale studies [26,414]. Our results also showed route fidelity among individuals passing Western Australia. Dispersal (own path preferences) in the Indian Ocean as well as high residency in Banda Sea were identified (Fig. 5.2). Such route fidelity during migration, dispersal and high residency were previously reported for baleen whales [94,188,369].

5.4.2. Home range and habitat models

We detected individual route preferences among whales during the migration in the Indian Ocean, but they ultimately converged towards the north along a wide corridor exceeding 500 km. This behaviour was also recognised in other baleen whale studies, and is suggested to be related to prey availability in relation to the dynamic environmental characteristics of different areas [27,125]. Whether this also is the case for PBW needs further investigation. When entering Indonesian waters, the whales utilised two adjacent separate migration corridors: one to the Savu Sea, and another to the Timor Trough. Therefore, corridor width is important when defining migratory corridors in MSP and MPA designation.

The fundamental driving forces of animal migration are typically resource availability, abundance and quality [27]. Animals move between habitats over time and space to acquire food, suitable mates, or shelter to avoid predation or adverse conditions [26,28]. Such temporary habitats may be separated by super large distances (up to thousands of kilometres) [15]. Memory of long-term average conditions seems to motivate the drive force of the blue whale migrations [415]. This may be due to the fact that suitable conditions for reproductive and foraging activities might be found in different areas, necessitating such migration activities [220]. Migration corridors, although they may contain low densities of animals at any given time, are therefore critical in allowing the animals to fulfil their lifecycles and maintain their genetic mixing [416] on an ocean scale.

Indonesian waters are potentially the winter breeding grounds for PBW populations [76,193], although further investigation is needed. The seasonal latitudinal migrations of blue whales between winter breeding and foraging grounds at higher latitudes are also reported in the eastern North Pacific of the northern hemisphere [24,228]. In our study, the PBWs show relatively high residency in the Banda Sea by wandering this localised area for >3 months during the SE monsoon season which coincides with the Austral winter. The wandering behaviour and high residency in this putative breeding habitat may enhance individual reproductive success [369] and is therefore relevant in possible temporal conservation management strategies for specific MPAs. The long residence periods of blue whales in certain areas also reflect foraging habitats [417]. The PBW migration routes were characterised by a series of core-use areas where whales travel slowly, connected by movement corridors through which whales travel quickly. The slow travel speed areas probably represent foraging areas [228,418]. Far-ranging movement between alternate foraging habitats is a favoured ecological strategy for blue whales [419,420], which also are non-fasting animals with large energy requirements [421,422]. It is highly likely that their migration pathways are directed by the occurrence of multiple alternate feeding areas as well, but this has not been studied yet.

Our analysis showed that PBW individual home ranges and core-use areas vary greatly in size and shape, while the overlapping core-use areas clearly show relatively small aggregation areas where the tracked population as a whole spent quite a lot of time. The concept of the Brownian Bridge Movement Model (BBMM) is based on the probability of an animal being in an area, and depends upon the time elapsed between the starting and ending locations, the animal's rate of movement, and the animal's tendency to range away from a straight-line path [129]. Larger variations in movement trajectories or increases in the scale of movement from local to ocean-basin driven by species' behavioural differences will result in changes in BBMM variance [129]. This mechanism may explain the variation in size and shape of home ranges and core-use areas in our study.

The BBMM showed that most of the indicated core-use areas were typically situated over the continental shelf in Western Australia and in deep waters in the Indian Ocean, Timor Trough, Banda Sea and Molucca Sea. Extended periods of time spent in those areas indicate that whales are using these habitats extensively for other activity such as foraging [128,423], although further research is needed to clarify this correspondence [418]. Because some core-use areas and migration corridors were used by more individuals than others, this could be used to steer conservation prioritisation (Fig. 5.2b).

Our habitat models (Fig. 5.3) indicated a distinct PBW seasonal movement pattern. The 'all year' model predicted a distribution with a high suitability of PBW habitat, also in several areas where telemetry data was not recorded such as in southern Java and southern Sulawesi. Given that a limited number of tagged PBW were used in our model, and that there were larger numbers of the whales than those used in this study, it is possible that the model predicts distribution where there were no records [112]. The suitable habitats could stay unoccupied due to anthropogenic disturbances or other factors such as the presence of apex predators [373], a matter that deserves to be further explored. Habitat models thus provide more comprehensive information than telemetry recorded points for incorporating into area-based management tools such as MPA and MSP.

Unlike the SE season model output that predicted distribution closely related to the presence data, the T1 season model predicted a discontinuity in distribution in the deep waters of the Indian Ocean, while there were some presence data recorded there. The environmental conditions (Supplementary Table S3) of this relatively small sample size (n <10% of total samples) that falls within these restricted areas are significantly different from that of the majority of the other records. This may explain why the Maxent model did not detect these relationships and subsequently predicted no occurrence. It is also possible that the whales react differently to their environment in stages of their migration so using the same relationships in the entire area may not match the actual situation [147]. Therefore, their unique environmental preferences were not recognised as the suitable habitat from the Maxent model outputs. This could occur because Maxent will give a higher habitat suitability score to an area that has similar environmental conditions as the majority of the training samples [175]. The discontinuity in distribution could also be due to the absence of other predictors that better represent the habitat preferences of the species but are not accounted for in our models.

The key environmental predictor in explaining PBW distribution in all models was sea surface temperature (SST) (Fig. 5.4). PBWs were predominantly associated with lower SST (23-25°C) during T1 in Australian temperate waters, and associated with higher SST (28-29°C) during SE monsoon in Indonesian waters coinciding with their use of the tropical habitat. This indicates niche switching based on distinct temperature during certain seasons. For many other cetaceans, SST is also the main factor influencing the geographical range [57,312,424]. The departure of whales from south to north coincides with the shift to colder waters (temperature-stress) in the southern region, and whales are presumed to search for warmer waters in the tropical region, despite the relatively high Chl-a concentrations in the south [389]. The whales' seasonal migrations from high to low latitude were reported to be driven by oceanic processes, species-specific thermal tolerances and shifts in prey distribution [220,266]. The SST is also known to capture the changes in water mass stratification [425], to enhance productivity, and to affect the availability of cetaceans' prey [185,296]. The start of the phytoplankton bloom also depends on temperature and light conditions [426].

The second most important predictor in predicting PBW distribution was distance to shelf. The PBWs migrate parallel to the shelf break (Fig. 5.1) and remained in the proximity of the Western Australian continental shelf, before they moved into deeper waters in the Indian Ocean and east Indonesia relatively far from the continental shelf. The upwelling waters around shelf breaks are reported to generate higher primary productivity and prey availability [427,428]. Blue whales often occur close to the shelf edge due to the presence of upwelling-modified waters [185] and this is true for Western Australia [193]. The absence of whale distribution in the Indian Ocean relates to the continental shelf in that the predicted distribution drops with increasing distance from the shelf.

Slope has been reported as an environmental predictor influencing blue whale distribution [292]. However, we only found a moderate relationship between slope and the PBW distributions for the 'all year' Maxent output. A steep slope increase, the complexity of the seafloor that is associated with dynamic currents and water mass exchange, and such high topographic complexity can increase local productivity and induce prey aggregation [268,292] that attracts top predators.

Although chlorophyll-a concentration (Chl-a) is known to be an indication of the productive areas [193,429], the PBWs in our study were more associated with SST rather than the Chl-a. This is supported by the departure of the PBWs to the warmer Indonesian waters when the temperature starts to drop in the south. Therefore, we only found a probably indirect, moderate relationship between Chl-a and PBW distribution in the SE model, when all whales occurred in deep Indonesian waters. Animals do not only occur in their preferred habitats, but may have reasons to use suboptimal areas [147]. Areas with high Chl-a (up to 19 $mg.m^{-3}$) are typically located in shallower coastal waters that are avoided by the whales. The areas occupied by PBW during the SE monsoon, however, still had relatively higher Chl-a (0.33 $mg.m^{-3}$) compared to the average Chl-a in the wider Indian Ocean (0.18 $mg.m^{-3}$) or Pacific Ocean (0.11 $mg.m^{-3}$) [430]. It is likely that the whales use patchy but highly productive areas with dense prey aggregations, primarily krill [193,431]. This phenomenon also occurred in other areas, for instance in the Azores, where blue whales interject their migration to harness localised areas of high productivity [214]. Chl-a, of course, can only predict the presence of PBW prey with a delay as the zooplanktonic grazer populations will peak with a time lag after the phytoplanktonic concentration peak. This time lag could be about 30 days [432]. This introduces a challenge in models as a derivative predictor needs to be designed [267,281,432]. Another reported constraint is that sometimes satellite Chl-a registration has a relatively poor spatial coverage due to cloudy days. Indonesian waters belong to a highly productive tropical upwelling system, where oceanic currents strongly influence the primary productivity [73,74] that serves as the building block for the pelagic food web, especially blue whales [193]. Upwelling is most evident along southern Java [433] and our models predicted this area as highly suitable habitats.

Our models did not identify distance to -1,000 m isobath as an important variable in predicting PBW distribution, therefore the predictor was not retained in any model output. Other studies, however, did find a relationship between distance to -1,000 m isobath and presence of PBW [418] or large whales in general [187]. For instance, the PBW appeared to perform foraging behaviour in deep waters around -1,000 m [418] and deeper than the continental shelf [193].

Our results revealed gaps in PBW protection over large important areas including PBW's migration corridors, core-use areas and suitable habitats. The fact that only <20% of the PBW's important areas are currently protected by MPAs, and >80% of migration corridors and core-use areas, as well as 60% of suitable habitats in Indonesia, are located outside MPAs, demonstrates an obvious shortcoming of the MPA network for this migratory whale in Western Australia and Indonesia. In addition, it is advisable to add the three important areas that are not yet protected and the additional 10% of the migration corridors outside MPAs in international waters to the PBW protection framework of MPAs. The size and shape of MPAs are a crucial feature for conservation management, with larger MPAs being relevant for protecting the migratory species [434], although there has long been debate about the effectiveness of large MPAs for these species [435].

Ideally, data on the distribution of individuals throughout their life cycle would be available to allow MPA network design to include important breeding, foraging and migration corridors [98,436], therefore properly delineating spatial and temporal boundaries around important habitats [107]. Not all parts of the PBW life cycle (e.g., the return migration) were represented in our models, because of absence of full life cycle telemetry data. A greater sample size that also covers full species life cycle is needed to more precisely identify the mismatches and to refine our insights about this migratory species. The initial design of an MPA should be informed by the movements and core-use habitats of the target species, to ensure that it covers sufficient critical habitats over its full biological cycle [15,434,437]. MPA networks consisting of small and large MPAs may increase their usefulness, although the level of restriction and associated enforcement in particular determine the efficacy of MPAs [438].

We revealed clear discrepancies between the designated migration lanes for large-whales in Indonesia and actual migration routes as suggested by this study (Fig. 5.5b,c). For instance, migration corridors in the Wetar Strait, Timor Trough and Molucca Sea (Fig. 5.5b,c; purple circles) are not currently included within the designated migration lanes. This is important information for managers for improving future migration lanes for large whales and optimising whale protection.

Since PBWs migrate seasonally, their foraging and migratory habitats often overlap with multiple anthropogenic threats at different times of the year. This would require mitigation measures over their entire range. For instance, the migratory corridors of PBWs along the Western Australia and Savu Sea largely overlap with the main shipping routes (Fig. 5.5b,c), since ships follow their habitual routes passing through MPAs in these areas. Mortality due to ship strikes is an important factor hindering the recovery of some whale populations from past over-exploitation [24]. Our results on spatio-temporal distribution of PBW in relation to marine traffic could inform improved management protocols (e.g., time-area closures or traffic adjustment) to reduce ship-collision in areas where there is currently a lack of observer coverage and enforcement [222].

5.4.3. Future perspectives and implication for management

Wide-ranging animals like PBW travel through the waters of multiple nations as well as in the areas beyond national jurisdiction (ABNJ) during different times of the year. PBWs may be subject to climate-induced changes in resources at different temporal and life cycle phases to which they must adapt [28]. This makes their conservation a challenge, requiring an understanding of spatio-temporal habitat use as well as coordinated action through multinational or international collaboration [98,222]. The PBW habitats and home ranges in this study, on the other hand, fall almost entirely within the EEZs of Indonesia, Timor Leste and Australia, making management for this species more straightforward through MPA establishment within EEZs. Such protection, however, is practically non-existent in most ABNJ or high seas, including several migration paths, where the lack of legal frameworks for making and enforcing MPA designations [439] hampers conservation efforts for marine migratory species. This situation means that the high seas are among the least protected places on earth [440].

Several international and regional initiatives regarding management of marine mammals are already established, and important steps forward can be made as discussed in Sahri et al. [308]. This includes the recommendation for Indonesia to involve itself in regional collaborations and to be a full member of the Convention on the Conservation of Migratory Species of Wild Animals (CMS) and the International Whaling Commission (IWC). For some species or populations, collaboration among just a few countries stemming from local or regional collaborations could help conserve specific, especially resident, marine mammal populations [222]. NGOs often play an important role in initiating these efforts. The PBW habitats and home ranges revealed in this study have recently been recognised to be important for conservation by an ongoing international conservation initiative, namely the Important Marine Mammal Areas (IMMAs) [350]. IMMAs are recognised for their importance, but do not receive any formal protection, unless declared as such by a national authority. This recognition highlights the need for protecting these important yet vulnerable areas through management measures following science-informed consideration.

Static area-based management approaches such as MPAs may still be unable to contribute sufficiently to migratory marine species conservation [441], while still impacting the interests of marine stakeholders, although political, economic and social feasibility are always taken into account as well [436]. Recently, new dynamic management approaches have been proposed such as time-dependent area closures or dynamic MPA networks, as a compromise between human and animal interests [98,441]. An example of this approach is the WhaleWatch program, which although not established as an MPA, fulfils the criteria in terms of spatial protection of blue whales from ship strikes [181]. Dynamic MPAs that target predictable habitat traits, such as temperature fronts to delineate migration corridors of loggerhead turtles in the central Pacific, may be more appropriate for management [98]. Spatially explicit measures advised by real time surveys and tracking, e.g., right whale sightings and acoustic detections to inform shipping slow-speed zones in the eastern US [442], are also another good example of dynamic spatial conservation. By applying these techniques, protective measures could therefore entail dynamic spatio-temporal boundaries, with seasonally implemented protection and adaptive coordinates for protection, representing an improvement over conventional MPAs [218]. Limitations of dynamic MPAs do exist however, especially if they are implemented in situations with poor monitoring capacity and limited law enforcement.

5.5. Conclusion

This study demonstrates that available telemetry data can be used to model home ranges, core areas and probable migratory corridors using Brownian Bridge Movement Models. We were able to predict the suitable PBW habitat by modelling telemetry data against environmental predictors using Maximum entropy modelling. Consistent movement of pygmy blue whales from Western Australia to Banda and Molucca Seas in Indonesia demonstrated a high level of connectivity between the two regions. There is a discrepancy between the protected migration lanes in Indonesian marine spatial planning and the migration routes suggested by this study. The habitat models (all year and two seasonal models) revealed that large areas of suitable habitat are currently not protected, particularly along the international waters and within the Banda and Molucca Seas. The results can aid marine conservation planning by delineating important areas to optimise migratory species protection, with smartly delineated MPAs and new dynamic management approaches. The techniques we used can serve as a model approach for assessing the representativeness of MPAs for whales as well as other marine migrants worldwide for which telemetry data are available.

Declaration of interest

Authors declare no competing interest.

Acknowledgements

This work was financially supported by the Indonesia Endowment Fund for Education (LPDP) Scholarship from the Ministry of Finance of Indonesia for the first author [contract number: PRJ-482/LPDP.3/2017]. The authors thank Geert Aarts, Neftali Sillero, and Heather M. Williams for valuable inputs about habitat modelling and the anonymous reviewers who helped to improve the quality of this manuscript. The authors also thank the Ministry of Marine Affairs and Fisheries of Indonesia for MPA shapefile data, and the Authority of National Aquatic Conservation Areas (BKKPN) Kupang-Indonesia for the map of the designated migration lanes for large whales in Savu, Flores and Banda Seas.

Ethics statement

Ethical approval was not required for the current study, because the data were obtained from existing biotelemetry programs. The original biotelemetry program was conducted strictly according to the Australian law (see Double et al. [76]).

Data statement

The original telemetry dataset is publicly available and can be downloaded via: https://data.aad.gov.au/metadata/records/AAS_2941_blue_whale_Argos_sda_filter_tracks.

Supplementary information

Supplementary materials of this article can be downloaded at https://drive.google.com/drive/u/1/my-drive.

“When at sea, you must row (*your boat*) with the
oars you have got”

Dutch proverb

Chapter 6

Using cost-effective surveys from platforms of opportunity to assess cetacean occurrence patterns for marine park management in the heart of the Coral Triangle

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Published as: A. Sahri, P.L.K. Mustika, P. Purwanto, A.J. Murk, M. Scheidat. (2020). Using cost-effective surveys from platforms of opportunity to assess cetacean occurrence patterns for marine park management in the heart of the Coral Triangle. Frontiers in Marine Science, 7: 569936. https://doi.org/10.3389/fmars.2020.569936

Abstract

For Marine Protected Areas (MPAs) to be effective in conservation, their zoning and management needs to be based on scientific data. Obtaining information on spatio-temporal occurrence patterns of cetaceans can be especially challenging. This study used platforms of opportunity (i.e., fishing monitoring vessels) from May 2004 to May 2012 as a cost-effective way to address this knowledge gap in the Wakatobi National Park (WNP) at the heart of Coral Triangle, an important area for cetaceans in Indonesia. A database was created of cetacean sightings per surveyed days at sea, allowing for an analysis of species diversity and habitat use around the islands. Of the 11 cetacean species identified, spinner and bottlenose dolphins were sighted most often, followed by melon-headed and sperm whales. Spinner dolphin showed a wide distribution in the area, whilst bottlenose dolphin and melon-headed whale occupied the waters between the main islands and south atolls. Sperm whales occurred mostly in waters north of the main islands and as melon-headed whales, mostly in deep waters. Most cetacean sightings occurred in the zones designated for human use, indicating where potential conflicts might occur. No sightings were found in the Park core zone, suggesting a mismatch between WNP design and the cetacean ecological needs. Based on a sub-sample of the dedicated fishing monitoring sightings, a sighting frequency was derived. Small and large cetaceans were reported mostly during inter-monsoonal seasons, possibly related to increased prey availability due to seasonal upwelling and increased survey activity. Inter-annual occurrence of cetaceans was variable, with no large cetaceans being sighted in 2010–2012, likely due to reduced survey efforts. In areas with limited resources for designated surveys, the use of platforms of opportunity can be a cost-effective tool to provide valuable data on cetacean occurrence. While data collection protocols in the WNP can be improved further, the results presented here already help identify potentially important areas as well as highlight where to direct designated research efforts. We advise to protect currently unprotected cetacean important habitats, and strictly regulate human activities in the current use zones for future WNP rezoning processes.

Keywords: cetacean, Coral Triangle, platforms of opportunity, marine park management, spatio-temporal occurrence

6.1. Introduction

Identification of areas of particular importance for a species is a key aspect in conservation and management of wildlife. This notion requires the acquisition of baseline information on species distribution and dynamics. Within management areas such as national parks, this data are a crucial input for designing effective spatial planning, to evaluate park zoning systems and to prioritise measures for protecting the species from adverse human impact. Obtaining this information can be particularly challenging for cetaceans. Many species migrate over long distances from their reproductive to their feeding grounds [24,220]. Others stay in smaller areas but move between offshore and inshore waters following prey [443,444]. While some species can be observed and identified easily due to their surface behaviour, others are highly elusive and very difficult to record [188,189]. Different methods can be applied to investigate how cetaceans use their habitat and their applicability depends mainly on the research objective and resource availability [126].

To cover large-scale areas, the most commonly used approach is dedicated aerial or ship-board surveys that follow a design of transects giving each sampling point in the study area an equal probability of being sampled (e.g., line transect distance sampling [126,155,207]). Conducting such an unbiased and elaborate survey generally involves dedicated vessels and observer teams and thus can be prohibitively costly [13,208]. An alternative in the case of limited resources (mostly funding constraints) is placing observers on vessels that serve as platforms of opportunity [208–210]. This is a low-cost method because generally no funding is needed for charter or fuel costs. Observers need to be trained for the work, but they can also consist of volunteers reducing running costs even further.

Platforms of opportunity can cover a specific route, such as for example ferries traveling regularly between harbours or cruise vessels following a set itinerary [208,210]. The advantage of this type of platform is that it provides samples of the same area repeatedly allowing a monitoring of cetacean occurrence over time. The disadvantage is that they are limited to a few number of transects that might not be representative of a particular study area. Where the ferry routes cross, for example national parks, the results can be used to inform management [43]. Other platforms of opportunity are less confined in their coverage, such as cetacean watching vessels [445]. Depending on the target species and limited by the range of the vessel, they cover a particular area with the aim to find cetaceans. This allows for a wider spatial coverage, but it also has the caveat that areas of assumed low density will get less coverage. Whale-watching vessels can stop long enough during an encounter to allow the collection of detailed information on group size, behaviour and the presence of calves [445,446]. Photographs can be taken of animals and used in large-scale databases to identify migratory routes and local occupancy of individual whales [447]. Assuming these vessels cover similar areas and the observer effort is also comparable over time, this data can provide an index of occurrence (e.g., sighting frequency) and inform on species diversity and behaviour. When collected over a long-term they are a valuable source of information on temporal and spatial changes in cetacean occurrence [213,214].

Indonesia has a high diversity of cetacean species [53], and was a popular whaling ground for large whales during the Yankee whaling era from the 18th to early 20th century [78]. The deeper eastern waters of this country are also an important migration route for cetaceans, including large whales [76]. Studies of cetacean species particularly around tropical oceanic islands are limited [448], including in Indonesia. These oceanic island cetacean populations likely have specific conservation needs, but these populations are not systematically monitored, particularly in remote areas [195] in waters with complex reef and small islands. Some information about cetaceans in Indonesia is available hidden in unpublished internal reports. Insufficient information on spatial ecology of cetaceans impairs effective conservation strategies in this country.

Wakatobi at the heart of Coral Triangle region and part of the Banda Sea ecoregion is the second Indonesian national priority for area conservation [72]. Wakatobi is characterised by complex reefs and small-islands with a diverse submerged topography comprising a continental shelf, slopes, and pelagic waters with trough-, ridge- and seamount-like features. These characteristics are known to influence ocean circulation, induce nutrient upwelling and provide a diversity of water masses resulting in a rich habitat complexity, high biodiversity and great abundance for many species including cetaceans [449,450]. The unique configuration of near-shore yet deep-sea habitat of Wakatobi is of special importance to deep-sea cetacean species, making the area one of the most important marine systems in Indonesia. Wakatobi waters were therefore designated as a marine park in 1996 [451]. The near-shore deep-sea cetacean habitats in Wakatobi provides a unique opportunity to survey deep-water cetacean species that normally occur in waters further offshore, which would otherwise be too challenging to monitor with small boats (e.g., in Malaysian waters [444]). However, there is significant fisheries activity [452] and the effectiveness of the marine park as a conservation tool for cetaceans is not known.

Unfortunately, as in other regions of Indonesia, data availability on the status of cetaceans in this regionally important habitat [72] is very limited, posing big challenges for cetacean conservation and management. Neither cetacean diversity nor the spatio-temporal occurrence of the different species is known for Wakatobi waters. In addition, the habitat preferences of the cetaceans in this area in terms of seafloor topography such as reef habitat types and depth have not yet been described in detail. This lack of information hampers informed conservation efforts within the area. To address this issue, a cetacean monitoring program was initiated in the Wakatobi National Park (WNP) and adjacent waters in 2004 and cetacean sightings were documented until 2012. The program aimed to assess cetacean species diversity, reveal spatio-temporal occurrence patterns and their habitat type preferences. The initiative for gathering such information was required by the WNP Management Plan document [451].

Cetaceans can in different ways susceptible to anthropogenic threats. The threat of adverse human impact especially occurs from spatial and ecological overlap with human activities [208]. Important human disturbances include direct (bycatch) and indirect (prey depletion) impacts from fisheries [39], as well as physical and acoustic disturbance mainly by marine traffic [43,44], seismic activities from oil and gas exploration and naval sonars [46,47], and various sources of pollution [48–50]. Increasing anthropogenic stressors include coastal-offshore development and energy production, resource extraction, tourism, and climate change [57,58]. To assess the potential impact from these human threats, baseline information on cetacean occurrence at a local level is urgently needed.

Our objective was to develop an approach to use platforms of opportunity as well as incidental data from long-term visual monitoring to add knowledge of unstudied cetaceans populating oceanic island-based habitats of Wakatobi. This approach provided information on the diversity, spatio-temporal occurrence patterns, and relative abundance of cetaceans in the area of interest. By comparing the spatio-temporal occurrence patterns with bathymetric characteristics and reef habitat types, we also revealed habitat preferences of these cetaceans. Finally, we discussed the advantages and caveats of using non-systematically collected data, and the implications of our approach and findings for effective cetacean conservation, spatial planning and marine park management.

6.2. Materials and Methods

6.2.1. Study area

The study area encompasses WNP and adjacent waters, centrally located within the Coral Triangle region, a region with exceptional marine biodiversity [69]. The park includes a remote island group, approximately 120 km off the southeast Sulawesi mainland (Fig. 6.1). The area is one of the largest marine parks in Indonesia and covers approximately 13,900 km^2, containing all the major reef types. WNP includes four major islands with the boundaries are congruent with those of the Wakatobi district government [451]. The area has a diverse and complex submerged topography with channels between major landmasses that serve as passages for migrating mammals [451]. The area has a relatively narrow continental shelf and the depth increases very rapidly from the shelf edge at around 150 m from the shorelines. The oceanographic conditions are influenced mainly by circulating and seasonally changing currents in the Flores and Banda Seas and result in productive and relatively cool waters as a consequence of upwelling from the south [451].

6.2.2. Data collection

Cetacean data were collected from May 2004 to May 2012 following a cetacean monitoring protocol developed by the WNP Authority and The Nature Conservancy-World Wildlife Fund for Nature (TNC-WWF) Joint Program Wakatobi. Briefly, the protocol was applied by trained personnel mainly during Resource Use Monitoring (RUM) trips conducted to collect data on fishing activity. Other platforms of opportunity used were vessels conducting diverse monitoring programs (reef health, turtle, seabird, spawning aggregation site), the tuna tagging program, VIP guest trips, trips to outer Wakatobi, incidental patrols, and inter-island cruises; thus making the cetacean surveys cost-effective. Sightings reported by fishermen and volunteers were included as incidental sightings.

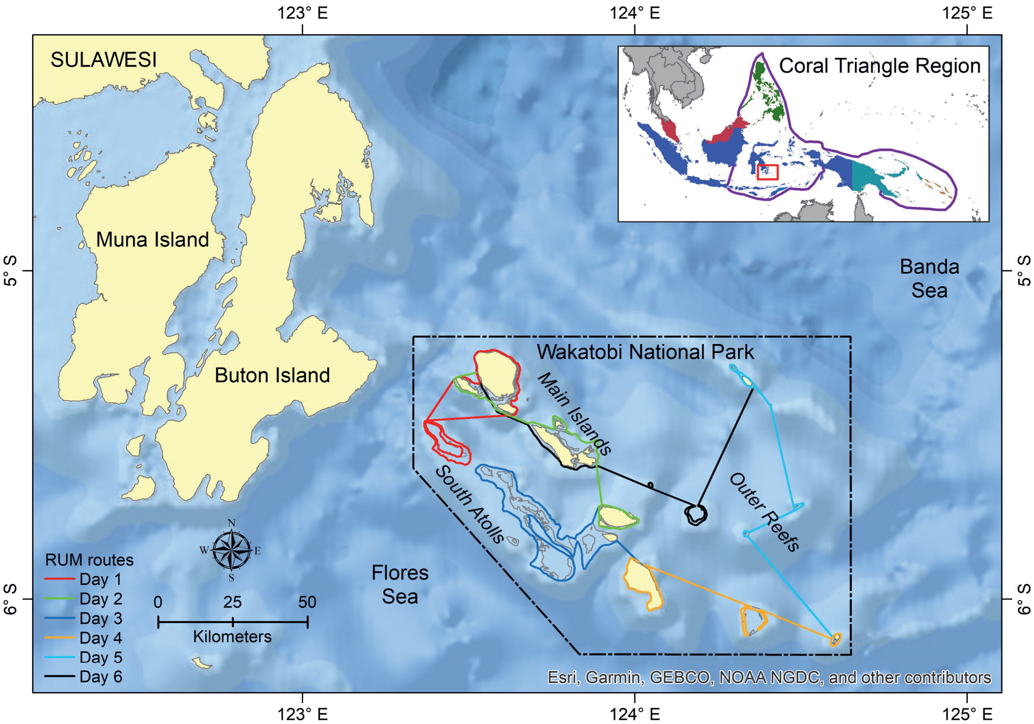

Fig. 6.1. Study area in Wakatobi National Park (WNP) and adjacent waters. The routes of Resource Use Monitoring (RUM) as a main platform-of-opportunity survey are presented as coloured lines.

Different fleets were used as observation platforms, including some speedboats (length ~4 m; height 0.5–1 m; speed ~20 knots); and "Floating Ranger Station" liveaboards (length ~20 m; height 3–5 m; speed 7–9 knots). Travel speed was not constant depending on navigation, boat type and weather conditions.

The RUM was designed to cover all habitat types within the WNP (i.e., main islands, south atolls, and outer reefs), and took 6 days to complete by following fixed line transects (Fig. 6.1). However, the boats did not always follow the predetermined survey routes due to technical issues e.g., logistics and supply, vessel reparation, and weather constraints. This arrangement resulted in changes to the fixed routes and difference in area coverage between surveys. In 2007 and 2008, several surveys could be conducted in 1 month, resulting in the higher sum of surveyed days per month (a complete trip suggested by the protocol).

Cetacean observations took place en-route between the harbour of origin and the destination (e.g., fishing locations, location of targeted monitoring) as well as en-route between destinations. Search efforts were suspended during the RUM interview stops or when a targeted monitoring had to take place. At least one observer maintained visual watch during daylight hours (06:00–18:00 h, weather permitting). Searching was primarily done with the naked eye or sometimes with the aid of hand-held binoculars. The observers were trained and experienced in cetacean data collection and identification, although their abilities varied and it cannot be guaranteed that search effort was continuous in all cases. All records were quality controlled by experienced observers that were onboard to ensure that the methodology was as consistent as possible between observers. Surveys also recorded days at sea with no sightings. Because the method does not follow a standardised distance sampling protocol [207], all sightings recorded during these surveys were categorised as "opportunistic."

When a cetacean group was detected, the boat slowed down or stopped, and information was recorded on a standardised form. This form included entries for geographic position, time of sighting, species identity, number of individuals, and observer name(s). In the form, estimated distance and relative angle from the vessel to the cetacean group at the time of the sighting were noted as well as specific behaviour and other remarks, although not all observers recorded all this information. A cetacean handbook was used to aid in the identification of sightings to the species level. When species identification was questionable, photographs were shown to other cetacean experts working in the region. If identification was not possible on a species level, the sighting was recorded as dolphins, whales or unidentified cetacean. Unidentified species can be caused by a combination of factors, such as very short encounters, distance of the sighting, no clear appearance of the cetacean, or lack of observer identification skills. Weather conditions were not consistently recorded each day and records were not always provided with a sea state description (e.g., Beaufort scale), although outstanding sea conditions including rain, strong wind, and high waves were usually recorded. Vessels did not go out when weather condition were so bad (approximately Beaufort >4) that they would hamper the vessels to conduct their work.

6.2.3. Data analysis

6.2.3.1. Survey efforts

The survey set-up did not facilitate the collection and storage of continuous GPS data, so information on km tracks or search hours per day was not recorded. The best available proxy for survey effort was survey days at sea. For each survey day, information on cetacean sightings, including days with no sightings, were available. The limitations of the data in terms of survey coverage and number of sightings meant it was not feasible to compare the results from outside and inside WNP. Therefore, we treated our data (inside and outside WNP) as one dataset. All data that included effort information were considered to be part of the "eligible survey" dataset.

An eligible survey was defined as any trip that consisted of four (equal to two third of a complete trip suggested by the monitoring protocol) or more days. This subset of the available data made the different surveys more comparable in their area coverage and applicable as a proxy of effort. Using both "days with" as well as "days without" sightings per survey allowed the calculation of a relative sighting frequency (of both sightings and individual animals).

6.2.3.2. Datasets used

All cetacean sighting records were quality-checked and placed in a database. This information was used to provide a species record for the area and to describe the presence only occurrence for each species. With this data filtering, the number of surveys for calculating sighting frequency (i.e., number of sightings per survey day) was reduced to 103 (74%) surveys from the original 140 surveys. The number of sightings was also reduced to 241 (67%) sightings from the original 358 sightings. Therefore, we combined the sightings based on higher taxa and defined large cetaceans (baleen and sperm whales) and small cetaceans (the rest taxa). The sighting frequency was averaged per survey and then monthly and annually.

To understand a possible determinant to the inability to identify cetaceans, we conducted logistic regression [453] between the dummy variable of unidentified cetaceans and several independent variables, i.e., the distance between the animals and the observers, the number of animals encountered in a group and season. We could not examine the association between other variables (e.g., the encounter period or observers' skills) due to the absence of such data.

6.2.3.3. Spatial and temporal occurrence patterns

All sightings that were obtained from all survey days at sea were combined into a single dataset. ArcGIS 10.6.1 (Environmental Systems Research Institute, Inc.) was used to visualise species spatial distribution or occurrence patterns maps based on sighting locations and number of individuals. Sufficient sightings for depicting spatial occurrence patterns were only available for the four most abundant species: spinner dolphin, bottlenose dolphin, melon-headed whale, sperm whale, as well as two unidentified taxa (dolphins and whales). The cetacean occurrence was correlated to the current park zoning system, reef habitat types, and depth preferences to assess area preference. Depth data were extracted from the General Bathymetric Chart of the Ocean (GEBCO, https://www.gebco.net/). For investigation of the temporal occurrence patterns, sighting data per species were grouped by month from all survey years. The sighting data of the four most abundant species described in this paper were also used to analyse the habitat suitability of these species in another paper using a more complex habitat model.

6.2.3.4. Additional important information

Information on cetacean behaviour, mother-calf pairs, and cetacean-fishing vessel and fish aggregation devices (FADs) interaction was not always recorded for each sighting. Since the amount of additional data was limited, no inferential statistical analysis could be performed, therefore it only was reported descriptively. Behaviour of cetaceans was classified into four categories: (i) traveling–normally moving animals on a steady course, (ii) resting–stationary in one place, almost without movement, (iii) socializing–clear and constant interaction between the animals in a normally stationary group, and (iv) foraging–non-synchronised movements and very active animals, normally involving the visualization of prey or aggregation of birds [446]. We added (v) “bow riding” as a special category, since the behaviour is prevalent in small cetaceans, and it shows a cue of being attracted to vessels [454].

6.3. Results

6.3.1. Efforts and sighting summary

A total of 671 days were surveyed from May 2004 to May 2012 of which 229 days were with sightings (Table 6.1). The total of 358 sightings corresponds to 12,846 individual animals. Surveyed days at sea were relatively consistent over the years, although only in 2007 and 2008, all months of the year were covered (Table 6.1, Fig. 6.2, and Supplementary Fig. S1). Although the months in which surveys were performed included all four monsoonal seasons, most effort was concentrated in inter-monsoonal (transition) seasons characterised by calm weather (Fig. 6.2): from March to May (Transition 1 season, before SE monsoon) and September to November (Transition 2 season, before SW monsoon). The remaining months are mainly associated with rough weather, particularly from the end of June to August (SE monsoon).

Table 6.1. Summary per year of cetacean survey efforts (using all dataset) and cetacean sightings and numbers in Wakatobi National Park and adjacent waters.

Year	No. of surveyed months*	Total no. of surveyed days	No. of days with sightings	No. of sighting events	No. of sighted individual cetaceans
2004	6 (8)	30	15	20	454
2005	9 (12)	72	36	50	1,032
2006	7 (12)	93	30	41	1,944
2007	12 (12)	195	51	75	3,058
2008	12 (12)	141	32	46	2,310
2009	6 (12)	70	21	34	1,481
2010	8 (12)	36	23	36	1,392
2011	5 (12)	21	17	51	1,032
2012	3 (5)	13	4	5	143
Total	68 (97)	671	229	358	12,846

*Number in parentheses indicates the number of complete months should be surveyed for that year. Only in 2007 and 2008, all months were surveyed. The study period lasted from May 2004 until May 2012.

6.3.2. Cetacean diversity

Eleven species were positively identified in the WNP and adjacent waters during this study, which accounts for 37.4% of all sighted cetaceans. Among the identified species, eight were small cetaceans and three were large whales (sperm, Bryde's, and blue whales) (Table 6.2). The four most frequently sighted species were spinner dolphin (17.6%), bottlenose dolphin (7.5%), sperm whale (5.6%), and melon-headed whale (3.6%) (Table 6.2). The sightings of these four species comprised 34.4% of the total number of sighting events. Each of six other species only represent less than 1% of the sightings, while the majority of the sightings (55.3%) were unidentified dolphins (Table 6.2).

The order of most sighted species based on the number of individuals was a bit different for the first four highest ranks: spinner dolphin (25.3%), bottlenose dolphin (10.4%), melon-headed whale (6.9%), and Pantropical spotted dolphin (2.1%). The greatest proportion of individuals reported were unidentified dolphins (53%). The identified cetacean species mostly have the IUCN status of "Least Concern" (five species) and "Data Deficient" (three species) (Table 6.2). Observations of less commonly sighted cetaceans also contribute to species presence information for endangered and vulnerable species in Wakatobi waters i.e., blue whale and sperm whale.

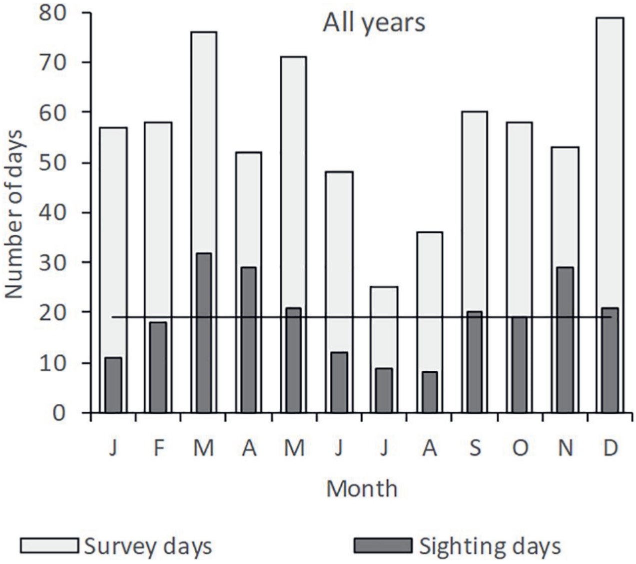

Fig. 6.2. Total monthly survey efforts (number of survey days) and numbers of days with cetacean sighting during the Wakatobi cetacean monitoring program from May 2004 to May 2012. Horizontal line (–) indicates mean number of days with cetacean sighting over all months. T1, Transition 1 season (March–May); SE-Mons, SE Monsoon season (June–August); T2, Transition 2 season (September–November); SW-Mons, SW Monsoon season (December–February).

Table 6.2. Summary of cetacean species sighted in Wakatobi and relative number of sightings and individuals (in relation to total n) from May 2004 to May 2012. IUCN (www.iucnredlist.org) status: DD, Data Deficient; VU, Vulnerable; NT, Near Threatened; LC, Least Concern; n.a, not available.

Common name	Scientific name	IUCN Status	Sightings		Individuals	
			n	%	n	%
Spinner dolphin	*Stenella longirostris*	DD	63	17.6	3,244	25.3
Bottlenose dolphin*	*Tursiops truncatus* *Tursiops aduncus*	LC DD	27	7.5	1,340	10.4
Sperm whale	*Physeter macrocephalus*	VU	20	5.6	54	0.4
Melon-headed whale	*Peponocephala electra*	LC	13	3.6	890	6.9
Pantropical spotted dolphin	*Stenella attenuata*	LC	3	0.8	270	2.1
Short-finned pilot whale	*Globicephala macrorhynchus*	DD	3	0.8	140	1.1
Cuvier's beaked whale	*Ziphius cavirostris*	LC	2	0.6	3	<0.1
Risso's dolphin	*Grampus griseus*	LC	1	0.3	5	<0.1
Bryde's whale	*Balaenoptera brydei*	n.a	1	0.3	4	<0.1
Blue whale	*Balaenoptera musculus*	EN	1	0.3	1	<0.1
Unidentified dolphins			198	55.3	6,813	53.0
Unidentified whales			26	7.3	82	0.6
All species			358	100	12,846	100

* During monitoring, the observers recognised two types of bottlenose dolphins: Common- (*Tursiops truncatus*) and Indo-Pacific bottlenose dolphin (*Tursiops aduncus*), however no clear difference in visual appearance of both species was evident and they could mostly not distinguish both species. Therefore, hereafter we refer to both species as bottlenose dolphins or *Tursiops* spp. whenever applicable.

6.3.3. Spatial and temporal occurrence patterns

Overall, sightings were mainly concentrated in two geographic areas representing reef habitat types within the WNP i.e., inshore the main islands and south atolls, although some sightings were also observed in offshore outer reefs (Figs. 6.3 and 6.4A). Spinner dolphins were seen in all habitat types (Figs. 6.3A and 6.4A), while bottlenose dolphins and melon-headed whales occupied mainly the waters between the main islands and south atolls (Figs. 6.3B,D and 6.4A). Sperm whales were sighted mostly in the east of the main island bordering outer reefs and in the north part of the main islands, and tended to avoid the south atolls (Figs. 6.3C and 6.4A).

Most of the cetacean sightings (>90% for small cetaceans, >60% for large cetaceans) occurred in the zones of the WNP that are also used by people. The WNP Authority accommodates three zones based on the types of human activities: tourism zone, local use zone (only available for local fishermen), and general use zone (open for all, including fishermen from outside WNP with permits) [451], hereafter together indicated as “use zones” (Fig. 6.4B). The “no-use” zones can be divided in a core zone (no-go zone) and a marine protected zone (accessible but no human activities allowed). In addition to occurring in the use zones, sperm whale and unidentified whales were also prevalent outside the WNP zoning system (Fig. 6.4A,B). For all species and taxa, sightings seen within “no-use” zones were less than 2%, while no sightings were even found in the core zone (Fig. 6.4B).

Each of the four most sighted species had different depth preferences. Spinner dolphin and bottlenose dolphin mostly occupied shallower waters (depth median of −153 and −104 m, respectively), while sperm whale and melon-headed whale were mostly seen in the deeper waters (depth median of −816 and −762 m, respectively) (Fig. 6.5), and sperm whale especially along the steep slopes (Fig. 6.3C).

Seasonally, the number of identified cetacean species sighted was higher (>4 species) in March and April and from September to December, with a maximum of six species in November (Table 6.3). Only 2–3 identified species were recorded for the other months. Even though the data were collected through opportunistic survey platforms during all months, no successfully identified species was sighted in July (Table 6.3). Consequently, no single identified species was sighted year-round. Only in March, April, and November were the four most sighted species recorded (Table 6.3). No apparent temporal occurrence pattern was identified for the remaining six less sighted species.

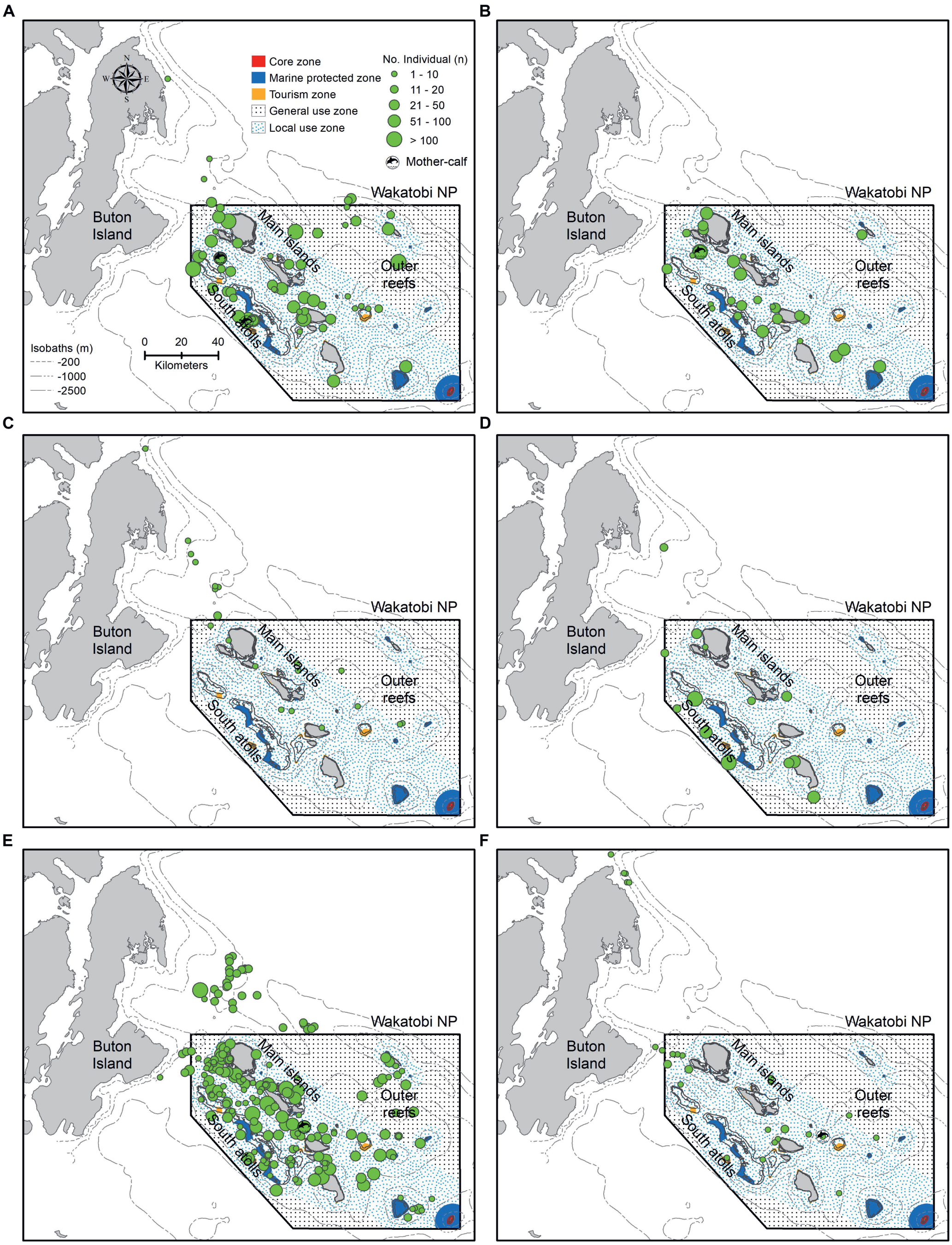

Fig. 6.3. Spatial occurrence patterns of cetaceans in Wakatobi based on sightings in the period of May 2004 to May 2012: (A) Bottlenose dolphin, (B) Spinner dolphin, (C) Sperm whale, (D) Melon-headed whale, (E) Unidentified dolphins, and (F) Unidentified whales. The depth contours (isobaths) and Wakatobi National Park (WNP) zoning system are presented in panel (A).

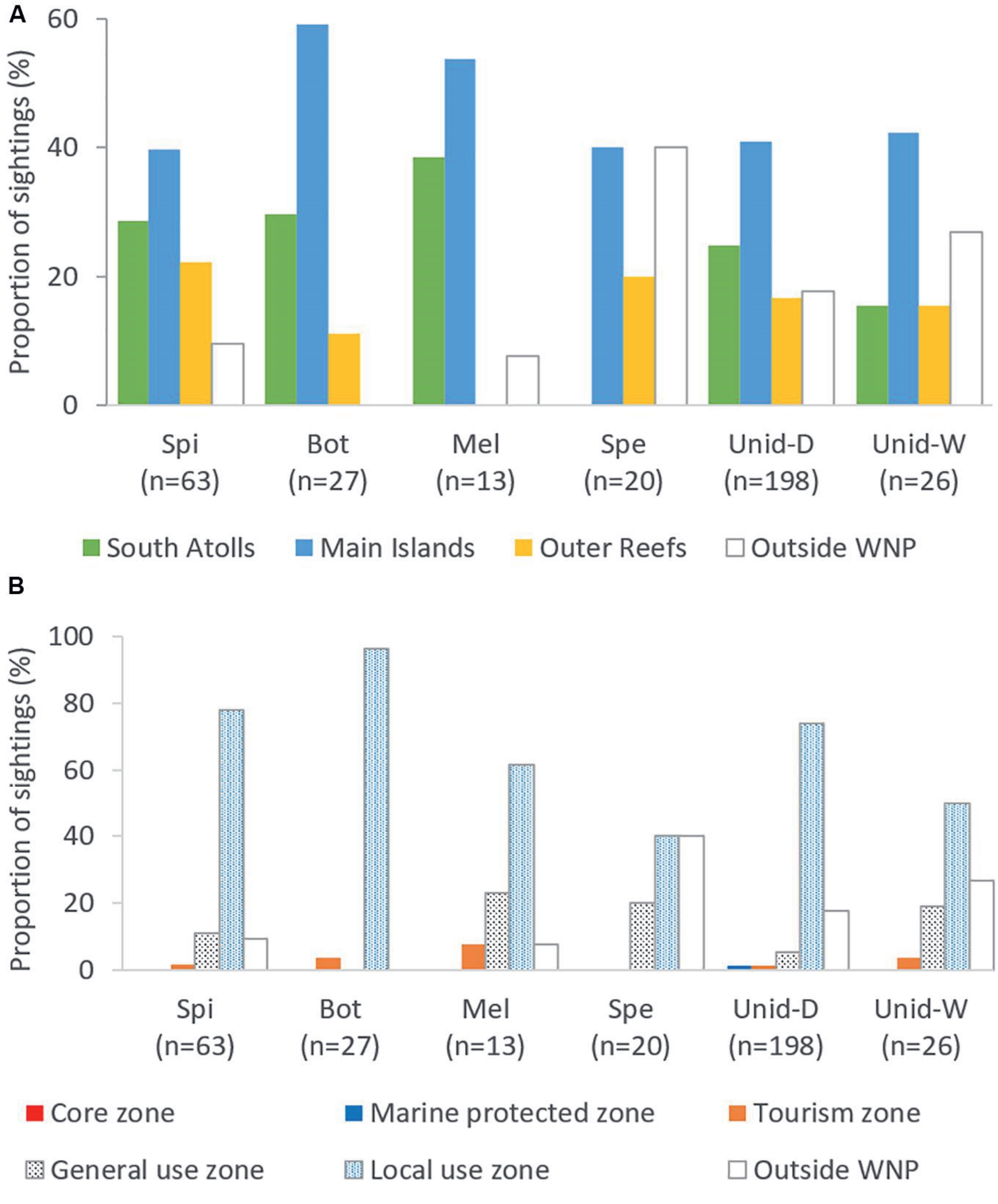

Fig. 6.4. Proportion of sightings based on reef habitat types (A) and WNP zoning system (B). Bot, Bottlenose dolphin; Spi, Spinner dolphin; Mel, Melon-headed whale; Spe, Sperm whale; Unid-D, Unidentified dolphins; Unid-W, Unidentified whales.

Table 6.3. Seasonal occurrence: whale and dolphin species sighted in different months between May 2004 and May 2012 in Wakatobi (using all dataset). (+) indicates species was sighted at least once during the month.

Species	Monsoon		T1 Season			SE-Monsoon			T2 Season			SW-
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Spinner dolphin	(+)	(+)	(+)	(+)	(+)			(+)	(+)	(+)	(+)	(+)
Bottlenose dolphin	(+)	(+)	(+)	(+)	(+)	(+)		(+)	(+)		(+)	
Melon-headed whale			(+)	(+)		(+)		(+)	(+)		(+)	(+)
Sperm whale	(+)		(+)	(+)						(+)	(+)	(+)
Pantropical spotted dolphin									(+)	(+)		
Short-finned pilot whale											(+)	(+)
Risso's dolphin					(+)							
Bryde's whale												(+)
Cuvier's beaked whale											(+)	
Blue whale										(+)		
No. of delphinid species sighted	2	2	3	3	3	2	0	3	4	2	5	3
No. of large whales species sighted	1	0	1	1	0	0	0	0	0	2	1	2
All species sighted	3	2	4	4	3	2	0	3	4	4	6	5

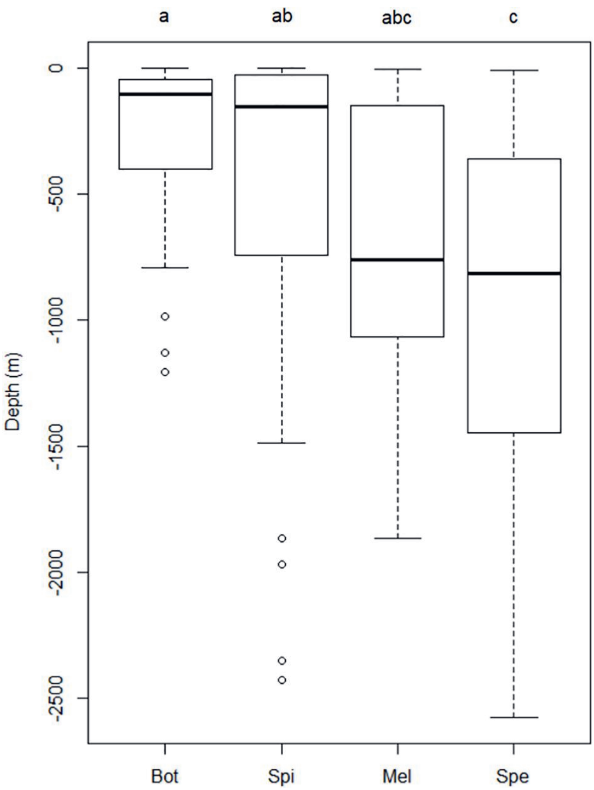

Fig. 6.5. Boxplots of sightings of four most abundant cetacean species associated with depth in Wakatobi: Bot, Bottlenose dolphin (n = 27); Spi, Spinner dolphin (n = 63); Mel, Melon-headed whale (n = 13); Spe, Sperm whale (n = 20). Significant differences of depth among species were checked using Kruskal–Wallis. Wilcoxon post hoc test was applied for multiple comparisons after Kruskal–Wallis testing indicated a significant difference. The same letters indicate the boxplots do not differ

6.3.4. Behaviours, mother-calf pairs and cetacean-fishing vessel interaction

From 193 sightings (53.63%), information on behaviour, mother-calf pairs or cetacean-fishing vessel interaction was recorded. Given that behaviours are species-specific, we showed the behaviour per species for four most sighted cetaceans (Fig. 6.6). Foraging and socializing were the two prominent behaviours in small delphinids (spinner dolphin, bottlenose dolphin, and melon-headed whale). Bow riding was prevalent in spinner and bottlenose dolphins. Only sperm whales were observed resting, although it is important to note that we only sighted three individuals for this species. For complete information on cetacean behaviours per species and taxa, see Supplementary Table S1.

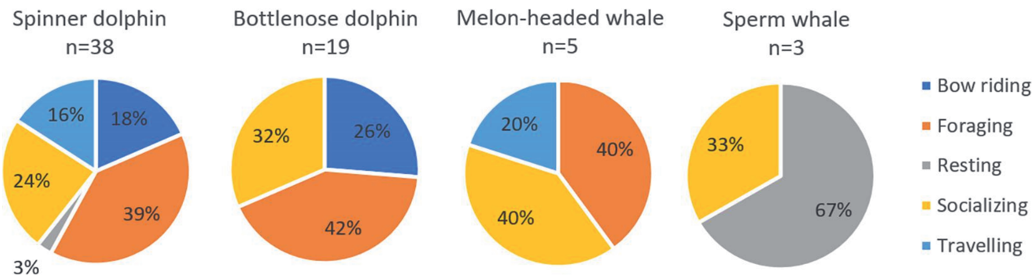

Fig. 6.6. Relative occurrence of each behaviour category for four most abundant species.

Cetacean sightings with calves were observed five times (1.4% of total sightings) during the course of study: twice for spinner dolphin, and once each for bottlenose dolphin, unidentified dolphins, and unidentified whales. In total, 13.4% of the sightings were associated with fishing vessels or FADs; all were small cetaceans consisting mainly of unidentified dolphins and spinner dolphin, and to a lesser extent pantropical spotted dolphin, bottlenose dolphin and melon-headed whale.

6.3.5. Opportunistic survey results (Sighting frequency)

A subset of all the surveyed days was defined as “eligible surveys” with comparable spatial coverage between months and years. The results showed that sighting frequency of large cetaceans was relatively constant, at around 0.25 sightings per day from 2004 to 2009, except for 2006 when it was <0.2 sightings per day. No sightings were recorded for large cetaceans in the last 3 years (Fig. 6.7A). Small cetaceans were seen regularly over the study period with the sighting frequency ranging from 2.25 to 4.33 sightings per day, with three peaks occurring in 2005, 2010, and 2011 (Fig. 6.7C). Monthly sighting frequency for both taxa showed a bimodal distribution, with peaks in September to November (Transition 1 season) and around March (Transition 2 season) (Fig. 6.7B,D). The monthly trend was quite similar both for large and small cetaceans, i.e., months with no sightings for large cetaceans tend to also have less sighting frequency for small cetaceans (Fig. 6.7B,D). The frequency of individuals per daily survey for both taxa can be seen in Supplementary Fig. S3.

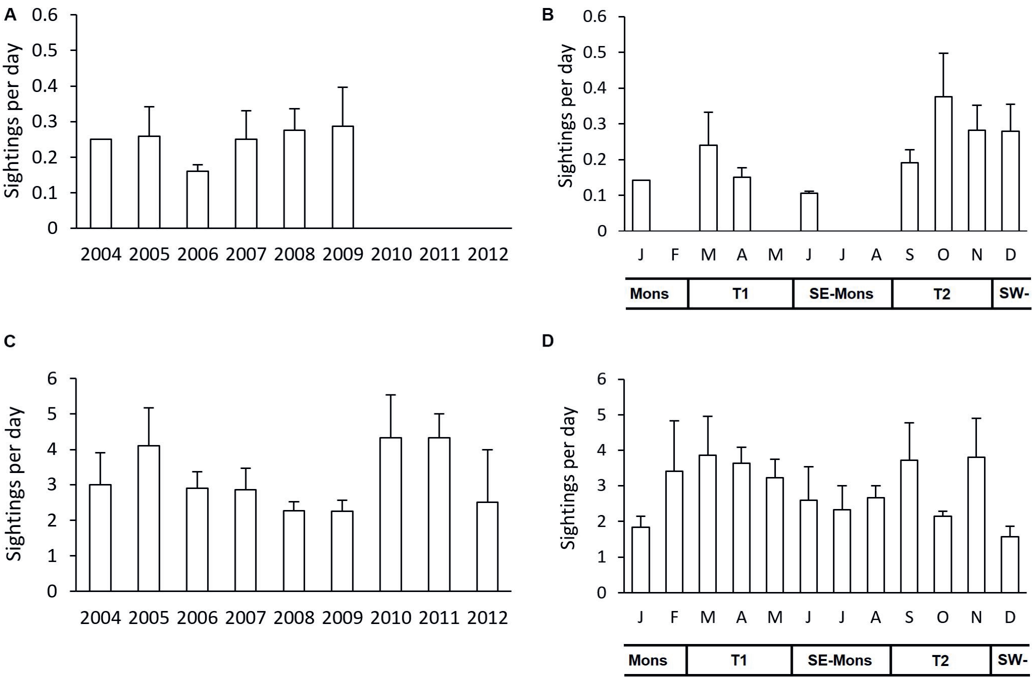

Fig. 6.7. The average sighting frequency per day for each year from May 2004 to May 2012 for large cetaceans (A) and small cetaceans (C); and by month for large cetaceans (B) and small cetaceans (D). T1, Transition 1 season (March–May); SE-Mons, SE Monsoon season (June–August); T2, Transition 2 season (September–November); SW-Mons, SW Monsoon season (December–February). The sighting frequency were calculated from a sub-sample of dataset with surveyed days of 4 or more days per survey. Error bars indicate standard errors.

Calculating the number of all cetacean sightings per year and month allowed for a temporal analysis of cetacean occurrence over time (Supplementary Fig. S2). The number of sightings for large and small cetaceans fluctuated greatly over the years with the highest numbers in 2007 and 2008 for both taxa (Supplementary Fig. S2A,C). Note that in 2004 and 2012, the survey efforts only cover parts of the year. The monthly sighting frequency (Fig. 6.7B,D) is related to the monthly number of sightings (Supplementary Fig. S2B,D). The total number of individual animals per year and per month for both taxa are presented in Supplementary Fig. S4.

6.3.6. Determinants to unidentified cetaceans

We conducted separate logistic regressions to examine possible determinants to unidentified dolphins (n = 198) and unidentified whales (n = 26), using season, distance between the observers and the animals and animal group size as the independent variables. Season and distance were not significantly associated with the prevalence of unidentified dolphins or whales. The number of dolphins per group per sighting was a significant determinant for the prevalence of unidentified dolphins ($p = 0.000$, $B = -0.240$, Exp(B) or ratio = 0.787), which was produced by a model with Block Chi Square = 56.650 (p model = 0.000, Nagelkerke $R2 = 0.364$). Using the same model setting, the number of whales per group per sighting was also a significant determinant for the prevalence of unidentified whales ($p = 0.000$, $B = -0.240$, Exp(B) or ratio = 0.787, Block Chi Square = 56.650, p model = 0.000, Nagelkerke $R2 = 0.364$). Thus, the smaller the number of animals per group was, the more likely it was that the species was unidentified (possibly because it was harder to identify the animal with only a few individuals being present).

6.4. Discussion

Marine Protected Areas (MPAs) can be a tool to conserve marine ecosystems as well as provide economic growth to local communities [455]. To be effective for cetaceans, MPAs need to be adequately designed, which includes the identification of areas suitable for multi-use and the exclusion of potentially harmful human activities. It is also very important to monitor changes over time, assess the effectiveness of conservation actions and be ready to adapt them when required [4].

Informed decision making within the MPA depends on reliable scientific data. Obtaining this for cetaceans can be challenging, but in some areas comprehensive research programs are in place (e.g., Stellwagen Bank in the United States [456]). In many MPAs, this type of rigorous monitoring cannot be followed due to logistical or financial constraints and alternative approaches are needed. In the following, we discuss the use of platforms of opportunity in WNP: the data obtained, challenges encountered as well as the opportunities this low-cost method provides to collect the valuable information on species occurrence needed to inform management decisions.

6.4.1. Cetacean Diversity

Information on cetacean species around Indonesia in the past has been primarily based on strandings [193,194] and incidental sightings [77]. Only recently, cetacean monitoring programs have been conducted in several sites in Indonesia, greatly increasing our knowledge on cetacean diversity. The numbers of species identified were 22 in Papua, 27 in East Kalimantan and 28 for wider Lesser Sunda [37,55,195,457]. For Wakatobi waters, the limited multi-species studies on this taxonomic group are only available in grey literature. This study is the first to provide important baseline information on the ecology and the community patterns of cetaceans. Eleven cetaceans were positively identified at species level representing 32% of all cetacean species recorded in Indonesia [53]. These include species featured in the International Union for Conservation of Nature (IUCN) Red List of Threatened Species [229] as Endangered (blue whale, *Balaenoptera musculus*), and Vulnerable (sperm whale, *Physeter macrocephalus*). Almost two thirds of the identified species are listed as Least Concern or Data Deficient, the last category making it difficult to assess their population status.

Wakatobi National Park has a high habitat diversity which is reflected in the large number of species recorded. This finding highlights the important role of Wakatobi waters as a regional reservoir of cetacean diversity. Throughout the study period (from 2004 to 2012), 90% of the species had been identified within the first 5 years indicating that even with the non-systematic coverage, the most prevalent and possibly resident species were detected early in the study. As the majority of sightings (62.6%) were recorded as unidentified dolphin or whale species, there are probably still a number of undetected species. Even during dedicated surveys, identification rates for small cetaceans can be below 50% [458]. This can be improved by training of observers in species identification and taking photographs of the sightings.

6.4.2. Sighting frequency

Assuming that survey effort is roughly similar between surveys, the sighting frequencies can provide a long-term measure of occurrence and changes for a study area. These results tend to be more quantifiable than studies that only use incidental sightings with no associated effort data [126], or are based on perceived trends of cetacean abundance reported by fishermen [459].

The sighting frequency in Wakatobi was about tenfold lower for large cetaceans (0.25 sightings per day) than for small cetaceans (2.25–4.33 sightings per day). A similar relationship was found in the Halmahera Sea and the Pacific Ocean part of North Papua with 0.016 sightings/km for small cetaceans (25 sightings) and 0.003 for large cetaceans (five sperm whale sightings) [460]. Large whale encounters primarily consist of sperm whales and these occur almost exclusively in deep water habitats. The sighting probability is linked to the coverage of potential sperm whale habitat, which as stated earlier is quite well accessible in Wakatobi waters.

In this study, sighting frequencies were used for a subset of the data which allowed the investigation of temporal changes in cetacean occurrence between seasons and years for Wakatobi waters. The reduced number of records made it necessary to pool all sightings into either the category small or large cetacean. The sighting frequency for both small and large cetaceans, combined for the years 2004 to 2012, indicated a bimodal distribution with peaks in the two transition seasons, September to November and March. There are a number of possible reasons for the observed patterns. Weather conditions are calmer during the inter-monsoonal season than in the generally much rougher SE and SW monsoons [452]. As vessels generally only went out at sea to around sea states of Beaufort <4, the rougher seas should not have a large impact on sighting probability. However, for smaller groups of animals or those that are only visible for short times, the chance that an observer sees them will be reduced as soon as white-caps occur (Beaufort 3) [461]. This is in particular true for cryptic species such as beaked whales that occur in solitude or in small group sizes and are difficult to spot (and identify) even under good sighting conditions. For species that occur in large groups, approach vessels for bow riding and show active surface behaviour, such as spinner dolphins, the sighting probability would likely not change within this range.

The pooling of all species into either the category small or large cetaceans makes it impossible to determine in what way changes in distribution of different species within each category, e.g., due to changes in prey availability, might influence the overall pattern. This circumstance highlights again the importance of having a higher number of identified sightings which would allow for the investigation of species specific changes in occurrence, both throughout the year and interannually.

Survey effort was lower in the last three monitoring years due to limited resources at the end of the monitoring program (Supplementary Fig. S1). During those 3 years no large cetaceans were sighted (Fig. 6.7A). This is most likely because the offshore area received less survey coverage, especially in the outer reefs where large cetaceans were seen more often than in main islands and south atolls (A. Sahri and P. Purwanto, pers. obs.). For species sighted more rarely, such as large whales, a reduced effort can lead to no more animals being registered, thus making the calculation of sighting frequency impossible. Conversely, with the same survey effort around the much smaller inshore waters, the small cetacean density has increased in the last 3 years (Fig. 6.7C). For common species that are also sighted in times of reduced effort, such as spinner and bottlenose dolphins, the sighting frequency is likely a robust measure of occurrence.

Without further study though, it cannot be excluded that a decrease in number of sightings could also be related to depletion of the populations [462] or a change in distribution. It is important to use similar temporal and spatial coverage between years, even when using platforms of opportunity. The availability of abundance indices such as sightings per km or hour (rather than sightings per day, as used here) would also provide more refined insights into seasonality of cetacean presence in the study area.

6.4.3. Spatio-temporal occurrence patterns

The complex Wakatobi ecosystem attracts and supports a variety of cetacean species, because Wakatobi is located in the Indonesian tropical upwelling system, where oceanic currents strongly stimulate primary productivity [73,74]. In addition, the narrow and very steep continental shelf provides deep waters close to the shore, and the presence of submarine features around the coastline contributes to upwelling, thus further enhancing the productivity of the waters. The local depth and seabed configuration [463] in combination with oceanographic processes [464] are associated with aggregated cetacean prey species [337].

Typically, spinner dolphin, bottlenose dolphin, and melon-headed whale were observed in the vicinity of fringing reefs around the coastline, atolls and small islands. Spinner dolphin populations are known to occur in island and archipelago habitats and are often observed moving between coastal and oceanic habitats [443,444,460,465]. Bottlenose dolphins in the inshore area may have been *Tursiops aduncus*, while those observed offshore may have been *Tursiops truncatus*. These species are very difficult to distinguish at sea, in particular if they are not approached and/or photographed. Consequently, both species were recorded as bottlenose dolphin (*Tursiops* spp.). Bottlenose dolphins are known to form stable social groups, sometimes with small resident populations that have a high affiliation to a relatively small area, likely linked to high prey availability and low predation risk [466–469]. In Wakatobi, bottlenose dolphins occur wide-spread in the area on a regular basis, thus residency for at least some of these animals is likely. World-wide, bottlenose dolphin populations can be genetically distinct at small spatial scales, which is highly relevant for any conservation efforts [470]. The use of photographs of the dorsal fin of individual animals, as well as sampling of tissue for genetic analysis, could provide more insight into this.

Sperm whales were abundant in the vicinity of the submarine trough-like features between major landmasses [452] in the east part of the main islands bordering the outer reefs, and in the deep waters in the north of the main islands. This is to be expected as they feed mainly on mesopelagic squid and fish around the shelf edge [283]. Baleen whale sightings were comparatively rare, with Bryde's whales being sighted in one occasion. In contrast to other baleen whales, Bryde's whales do not conduct long-distance migrations, instead remaining in tropical and warm temperate waters all year [471]. They likely conduct movements to areas where breeding occurs, however, the general knowledge on the behaviour of this species is still poor [471]. Sightings around Wakatabi could indicate animals using this area on a regular basis, but further data are needed to confirm this.

Spinner and bottlenose dolphins occurred in Wakatobi waters 75% and 83% of the year, respectively. This is in line with the results from Bird's Head Seascape-Papua where spinner dolphins occurred during 92% of the year and bottlenose dolphins were seen 100% of the time [195]. In Solor-Lesser Sunda, spinner dolphins were also sighted almost continuously around the year (92%), but bottlenose dolphins less so (58%) [457]. Understanding the regional differences in the residency of these two species requires more designated research, including an improved identification of the two bottlenose dolphin species. Sperm whale occurred in Wakatobi waters 50% of the year round, comparable with the occurrence in Bird's Head Seascape-Papua (58%) [195] and was higher than that in Solor-Lesser Sunda (33%) [457]. Sperm whale females, calves and young males have been known to stay in the warmer waters of lower latitudes [283]. Adult males are thought to move between colder and warmer waters, although their seasonal migration routes are still not well understood. An analysis of historical whaling data indicate that they likely occurred year-round in Indonesian waters and in some areas showed a strong site fidelity [192]. Melon-headed whale occurrence in Wakatobi was higher (58%) than that in Solor-Lesser Sunda (17%) [457]. Just as sperm whales, this species tends to generally occur in deep offshore waters [472]. They are also sighted around island groups, examples in the Indian Ocean are the Comoros Archipelago, the Seychelles, the Maldives, and Sri Lanka [473–476]. A number of studies indicate that melon-headed whales around oceanic islands rest inshore during the day and move offshore during the night, likely following their prey [477]. This is similar to what is reported for spinner dolphins [186], but for either species, information on their detailed habitat use in Wakatobi is still lacking.

Only in July, each of three sightings of unidentified dolphins occurred in 2006, 2007, and 2010, much less than in other months. This could be related to the very rough Wakatobi waters in July in the middle of the SE monsoon limiting survey efforts (Fig. 6.2 and Supplementary Fig. S1). While one would, in general, assume that the productivity in the area was high during the summer, it could also be that this was not the case. There are a number of complex interactions, and in addition, human activities on land leading to a high input of nutrients, and the change in temperature due to climate change leading to a more stable stratified layer and less upwelling [478]. Monitoring of the physical processes, productivity as well as the occurrence of top predators would help to achieve a better understanding of the relationship between these factors in Wakatobi waters. Consideration of cetacean monitoring technologies that can also function well during the rough season, such as stationary passive acoustic devices, can clarify this issue [403,479].

6.4.4. Behaviours, mother-calf pair presence, and cetacean-fishing vessel interaction

Data on cetacean behaviour and group composition can help recognise areas important in their life cycle. Disruption of behaviours can increase the energy expenditure of individuals and potentially negatively impact their overall fitness and reproductive success (e.g., [480,481]). As an example, the presence of calves and the display of courtship behaviour help to identify reproduction grounds for migrating whales (e.g., [482,483]). For some species, preferred areas for resting and feeding can be identified, allowing protective measures to be taken [98,484,485].

Foraging behaviour of spinner dolphins in Wakatobi occurred in areas with a water depth of around −230 m. This is similar to the Sulu Sea were they primarily feed on mesopelagic fishes in depths of −200 to −400 m as well as squid and crustaceans

[486]. This species has been documented to follow the vertical movement of its prey [443,487] as well as to follow horizontal prey migrations between coastal and oceanic habitats [443,444,465]. There is no information available on what kind of prey spinner dolphins feed on in Wakatobi, thus how it influences their habitat choice remains to be investigated. Bottlenose dolphins foraged in areas with shallower depths around −60 m, which could reflect a specialization of different depth preferences between the two species related to physiological traits or to avoid prey competition.

Out of three sperm whales with recorded behaviours in our dataset, two of them were resting. Resting behaviour in large whales such as the sperm whales [488,489] needs to be considered in the WNP spatial planning due to the possible risk of collision [490] with ships that are using the same area. In addition to the aforementioned need for increased skills for species identification, the identification of species behaviour is also needed for future data collection. The presence of some cetacean mother-calf pairs suggests that the WNP provides nursery and calving grounds for several cetacean species.

Some of the small cetacean species are gregarious by nature. The largest group of cetaceans sighted during these surveys comprised of an estimated 200 individuals of spinner dolphins, in line with other studies reporting large groups of up to 500 [450] or even 1000 individuals [491]. Spinner dolphins are also known to show impressive surface behaviour, such as their “spinning” [492], making them highly visible. Two other species that were seen in groups of more than 100 individuals are melon-headed whale and bottlenose dolphin. Both spinner and bottlenose dolphins frequently approached vessels for bow riding. These charismatic and abundant species could potentially be the basis for ecotourism activities. Cetacean-watching can have great value if conducted in a responsible manner to avoid negative impacts on the animals [493]. Generating economic value for local inhabitants will help to motivate them to protect the marine communities.

During the surveys, skipjack tuna (*Katsuwonus pelamis*) were spotted at the surface exclusively around fishing vessels and fish aggregating devices (FADs), subsequently attracting small cetaceans (A. Sahri, pers. obs.). Dolphins tend to aggregate in such areas where their main prey occurs to increase their feeding success rate [494]. Fishermen in Wakatobi even use the presence of small cetaceans (mainly spinner and bottlenose dolphins) to locate the schools of yellowfin tuna (A. Sahri, pers. obs.) as has been described for other areas [495,496]. The co-occurrence between cetaceans and fishing activities increases the risk for cetacean entanglement and drowning [240]. Reeves et al. [32] suggested that local declines in small cetaceans are mostly due to increased intensification of fisheries and vessel activities. In addition, the co-occurrence with fishing activities may cause fish stock depletion for the cetaceans [491].

6.4.5. Limitations of using data from platforms of opportunity

The data collected with platforms of opportunity during this study come with some limitations that need to be considered when interpreting the information. One of the main challenges is the variable adequate temporal and spatial coverage of the study area.

Some platforms of opportunity, such as ferries, provide regular sampling opportunity over times, but their spatial coverage is limited. Other vessels, such as those used for whale-watching, focus on areas known for their high cetacean density to increase the chance of sightings. This shortcoming in representative coverage of an area can be addressed by using spatial or habitat suitability models [497,498]. In our study, the spatial effort could only be approximated as GPS tracks were not collected making it difficult to ascertain if survey coverage was similar between months or years. This means that there is a chance that the observed spatial patterns may reflect the distribution and abundance of the vessel effort rather than that of the animals.

The sighting probability for cetaceans is influenced by a number of known and unknown parameters. Our surveys varied in observation height, vessel speed, number of observers, search methods and observer experience. Weather conditions can also influence sighting probability, but as vessels did not go out in sea states of Beaufort >4, sighting conditions were relatively comparable between surveys. Ideally the impact of all (known) factors potentially influencing sighting probability are quantified and considered in the analyses [126,461,499]. In reality this is often not feasible. In our study, we could only calculate a simple sighting frequency per surveyed day used, likely leading to unquantified bias in the results.

Due to the lack of GPS tracks, sighting frequency could not be reported as the number of sightings per km or per hours surveyed, as is commonly done [446]. Instead, effort was recorded as days surveyed and the sighting frequency is reported as “sightings per day” (e.g., [500]). Assuming that sighting records are obtained throughout the study area, the results can still provide a good qualitative indication of the distribution and abundance of animals [501]. In our study, this assumption was made for a subset of data, i.e., mainly the fishery monitoring surveys, where more consistent information on spatial coverage was available.

Even considering these caveats, the data collected during the non-systematic surveys enabled the construction of a positively identified species list and a first indication of the cetacean population status and relative density. Although interpretation of non-systematically collected data is difficult without measure of effort [126], with stringent data filtering and quality control, valuable information can be obtained [463].

6.4.6. Implications for marine park management

Knowledge of cetacean population presence and ecology is fundamental for formulating conservation policy [502] and an effective policy depends on understanding relationships between species, habitats and anthropogenic interactions [503]. One of the most important approaches to marine conservation is the establishment of MPAs [504]. When managed well, MPAs designed for top predators as umbrella species are highly effective, resulting in higher biodiversity and more ecosystem benefits [8]. To identify areas of particular importance for specific species, baseline knowledge on the presence of cetaceans is needed [505]. The approach and findings derived from the platform of opportunity surveys can support the WNP Authority in their management of cetaceans within the MPA.

Wakatobi National Park was established with multiple-use zoning system, including two no-use zones (core and marine protected zones) and three use zones (tourism, local use, general use zones) [451]. Only ~3% of the total WNP area falls under the no-use zone, and this mainly concerns more sedentary coastal and marine ecosystems such as coral reefs, seagrass beds, mangrove, fish spawning aggregation sites and turtle and seabird nesting sites [451]. Actually, no sightings were found in the core zone of the WNP and >90% of small cetacean sightings and >60% of large cetacean sightings occurred in the use zones. This is a crucial finding that indicates the mismatch between WNP design and the ecological needs of the cetaceans.

The use zones are commonly highly used corridors by humans with traditional fishing, recreational activities and shipping taking place (Figs. 6.3 and 6.4) [38,113]. The potential adverse impact of these human activities on cetaceans can be addressed by setting and enforcing stricter rules such as only applying cetacean-friendly fishing gear, restricting vessel speeds and developing responsible ecotourism. The WNP Authority has set rules on fishing gear that is allowed to be used within the WNP [451], however no such a "code of conduct" is available yet for whale and dolphin watching tourism, even under the national legislation [308].

Improved information on behaviour and the spatial and temporal occurrence of cetacean species is urgently needed in WNP to inform the future management of specific threats to cetaceans and to identify appropriate areas for MPAs [504,506]. When cetaceans frequently use an MPA, cetacean conservation issues need to be included in the MPA management plan [503,507]. Information on cetacean ecology should be used to adjust the existing zoning system as an important step in balancing the needs of local users and those of protected species. Adjusting zoning designation of areas where threatening human activities significantly overlap with important cetacean habitat can contribute effectively to the species' conservation [508].

Large whales, especially sperm whales, occurred in the use zones as well as outside the WNP boundaries. The latter areas do not have any regulations in place to manage potential threats to cetaceans. MPAs that are predominantly designed for protection of coastal habitats and to support sustainable local fisheries may have little effect in protecting highly mobile cetaceans [111]. Designing protected areas for specific species requires knowledge of their spatio-temporal distribution and habitat requirements, in order to adjust the size of the management area to their ecological needs [508]. Both an adequate management regime [113] and MPA range expansion are needed, since the mobile animals usually have ranges that go outside of a single MPA [111,238]. An MPA network may be needed to truly protect these highly mobile species [98]. The possible connectivity between the Wakatobi cetaceans and those of the Flores and Banda Seas need further investigation to strengthen the cetacean conservation in the central and eastern waters of Indonesia. These areas have recently been recognised to be important for conservation by an ongoing international research and conservation initiative, named Important Marine Mammal Areas (IMMAs) [350]. This recognition highlights the need for protecting this unique and vulnerable area through the adoption of substantial management measures informed by scientific evidence. Information obtained from this study can also help inform national and local governments with data for cetacean species with different status from Data Deficient to Endangered under the IUCN Red List of Threatened Species [229]. Distribution and species diversity data, for instance, are recognised as critical for managing cetaceans in Indonesia [195].

We show that non-systematic low-cost survey data are a valuable information source in data-poor situations and where funding is limited. Relative occurrence, such as a sighting rate, if collected appropriately, is an adequate method for long-term monitoring and can provide the information needed to support improved park management and conservation planning. Some of the caveats that were identified during data collection can be easily addressed, such as the improvement of effort data by recording of GPS tracks and the collection of photographs for species identification. Recent software developments can facilitate data collection during non-systematic surveys and could be applied in WNP [509,510]. Data analysis and inferences based on non-systematic surveys need to take the limitations of the method into account. Where cetacean studies or wildlife-based ecotourism are just beginning, non-systematic surveys and collection of opportunistic sightings can provide enough information on animal occurrence that it can inform the kind of future studies that might be needed. We recommend that data collected from non-systematic, opportunistic, or incidental based projects be published to strengthen the value of volunteer efforts [511] and to maximise the benefit of such efforts for science and management [512]. When funds are available, designated surveys should be considered to obtain more accurate estimates of cetacean density and habitat use. Localised studies of cetacean species focusing on residence patterns, genetic structure, and population impacts arising from interactions with other anthropogenic threats, such as marine traffic, should yield additional information for management strategies at the local level.

This study showed the importance of the WNP for cetaceans and the necessity to obtain reliable scientific data to adequately manage this area based on validated, instead of assumed presence and migration routes. The use of platforms of opportunity provided first information on areas that are especially important to cetacean species and where conflict with human use might occur. The current survey approach can easily be adapted to collect improved data and it can also be used to inform future survey designs. Until more information on cetacean habitat use in the Wakatobi waters is available, we advise to consider protecting currently unprotected cetacean key-habitats as revealed by this study and setting stricter regulations for human activities in the current use zones during future WNP rezoning processes.

Conflict of interest

AS and PP were employed as monitoring coordinators by The Nature Conservancy (TNC) Indonesia to conduct sighting data collection. The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Acknowledgments

The cetacean data were collected by the Wakatobi National Park Authority and the Joint Program of The Nature Conservancy (TNC) Indonesia and WWF Indonesia. Authors would like to thank all Wakatobi National Park staff, Wakatobi District Government staff, speedboat captains and crews, monitoring staff, all volunteers who collected data in the field and especially Yusuf Fajariyanto for the data sharing agreement. The authors would like to thank the Indonesia Endowment Fund for Education (LPDP) Scholarship from the Ministry of Finance of Indonesia for financially supporting this study for the first author [Contract Number: PRJ-482/LPDP.3/2017]. The authors would like to thank Debby Barbé for the preliminary work she performed for this study and the reviewers who helped to improve the quality of the manuscript.

Data availability statement

The data analysed in this study are subject to the following licenses/restrictions: The data were obtained through a data sharing agreement from The Nature Conservancy (TNC) Indonesia and therefore are not publicly accessible. Requests to access these datasets should be directed to the corresponding author.

Supplementary information

The supplementary materials for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fmars.2020.569936/full#supplementary-material.

“Still, this is a big ocean, and researchers can never afford to look at very much of it.”

Moira W. Brown

Chapter 7

General Discussion

Conservation management of migratory species such as cetaceans is challenging, not only because regulations may not be optimally enforced, but also the knowledge of their population distribution and movement is limited. Indonesia is a cetacean hotspot and has the ambition to protect these species together with other marine biodiversity, as is obliged by national laws and also urged by global treaties. One of the management and governance options includes accommodating cetacean key areas (i.e., critical habitats and migratory corridors) into area-based management tools such as marine spatial planning (MSP) and marine protected areas (MPAs). Due to the lack of ecological information, however, this component has been largely neglected in the spatial planning. This PhD thesis aimed to develop an approach to provide information to improve cetacean conservation management in Indonesia through suggestions for strengthening the governance and introduction of habitat-use-based spatial planning by applying complementary methods and underused data. In the Chapters 2-6, the following four research questions were investigated: (1) What are the gaps and main shortcomings of the current legal framework in Indonesia for effective cetacean conservation, and what are the priority aspects to improve? (2) What is the cetaceans' spatial distribution in Indonesia and which environmental characteristics determine this? (3) What are potential migratory corridors and habitats of selected cetacean species and how do these relate to marine conservation systems and anthropogenic threats? and (4) How can cost-effective survey techniques support cetacean conservation planning by providing insights into spatio-temporal distribution and abundance of cetaceans in information-poor situations?

In **Chapter 2**, I reviewed the Indonesian marine mammal protection governance, legal framework, institutional arrangement, and related policies. The review showed that Indonesian marine mammal management policy adheres to most principles mentioned in five international conventions. The country's marine mammal governance has developed in 3 phases: 1970s (individual species are protected), 1990s onward (site-specific management), and from 2010 onward (wider marine management). Currently, no regulations are in place for traditional whale hunting, underwater noise pollution, no code of conduct for marine mammal tourism, and no standards for ex-situ conservation of marine mammals (e.g., in aquaria). It is remarkable how the regulations lack practical actions as well as the overlapping mandates among existing regulations. There are currently 7 policies available for marine mammal management in Indonesia. MPAs hardly used for specifically protecting marine mammals and there is an urgency to reinforce cross-institutional, regional and international collaborations.

Chapter 3 unveiled the antecedent seasonal distribution and habitat preferences of sperm whale using historical whaling data and two habitat models: Maxent and Generalised Additive Model (GAM). The predicted habitats were basically similar, although with different model performance metrics. In four areas in the eastern part of Indonesia, no seasonal differences occurred in sperm whale distribution, while noticeable seasonal differences were indicated in other areas. Sperm whale occurrences were determined by distance to coast, deep waters and submarine key features. The research also suggested drivers for local dispersion and site fidelity of sperm whale in the past, and improves our understanding of shifting baselines in species presence caused by intensive historical exploitation.

Chapter 4 presents current cetacean spatial distribution for 15 selected species in 7 ecoregions or seascapes based on habitat modelling using combined multi-source data. The results revealed a great heterogeneity in distribution among species, and within species among different locations. Areas rich in species were mainly related to coastal areas or insular-reef complexity, representing high productivity and upwelling-modified waters. Species traits such as deep diver or estuarine related species were clearly reflected in model outputs. Next, the overlap was assessed between cetacean key areas and current MPAs, MSP, and the anthropogenic threats: oil-gas concession areas and marine traffic. Although some potentially important cetacean habitats currently fall within MPAs, other areas are not and even overlap with oil-gas exploration activities and intensive marine traffic, indicating potentially high-risk areas for cetaceans.

Chapter 5 describes how telemetry-based home range and habitat modelling can predict pygmy blue whale's (PBW) migratory corridors and core-use areas, and then assessed overlap with MPAs and marine traffic. The study demonstrated a high level of connectivity between Western Australia and Indonesian Seas for PBW migration. Route fidelity, dispersal, and high residency of PBWs in certain areas were unveiled. Home ranges differed in size and shape among individual PBWs. There was discrepancy between the Indonesian designated migration lanes for large whales and migration routes revealed by this study. Large areas of migration corridors, core-use, and suitable habitats are currently not protected, partially lie in the high seas and overlap with intensive marine traffic areas.

In **Chapter 6**, cetacean diversity, spatio-temporal occurrence patterns, sighting frequency, and habitat preferences were assessed using non-systematic data (e.g., platforms of opportunity) from cost-effective surveys for marine park management in Wakatobi National Park (WNP), Indonesia. Of the 11 cetacean species identified, 4 species were most sighted. Spatial occurrence patterns of the most sighted species differed in their relation to reef habitat types, park zoning system, and depth. Temporal occurrence patterns of the most sighted species differed seasonally and sighting frequency varied seasonally and inter-annually. Additional insights in cetacean behaviour, mother-calf pairs, and fishing interaction were revealed. Most cetacean sightings occurred in the WNP use-zone and no sightings were reported in the park core zone, suggesting a mismatch between park zoning design and the cetacean ecological needs. The use of cost-effective surveys provided valuable cetacean data in areas with limited resources.

This general discussion provides the synthesis of the theoretical and empirical findings of the previous research chapters to be able to answer the research questions and formulate the conclusions of this thesis (as depicted in Fig. 7.1). I will first discuss how cetacean conservation governance can be improved and what aspects should be prioritised based on the analysis performed (7.1). Next, I will discuss main challenges and ways to fill the knowledge gaps in cetacean species distribution (7.2). I will indicate how historical and current cetacean spatial habitat modelling as well as cost-effective methods can aid in determining cetacean conservation hotspots and potential overlap with anthropogenic threats. Then, I will discuss how area-based approaches can be relevant for cetacean conservation management (7.3). Finally, I conclude this general discussion with future perspectives and recommendations for further research (7.4).

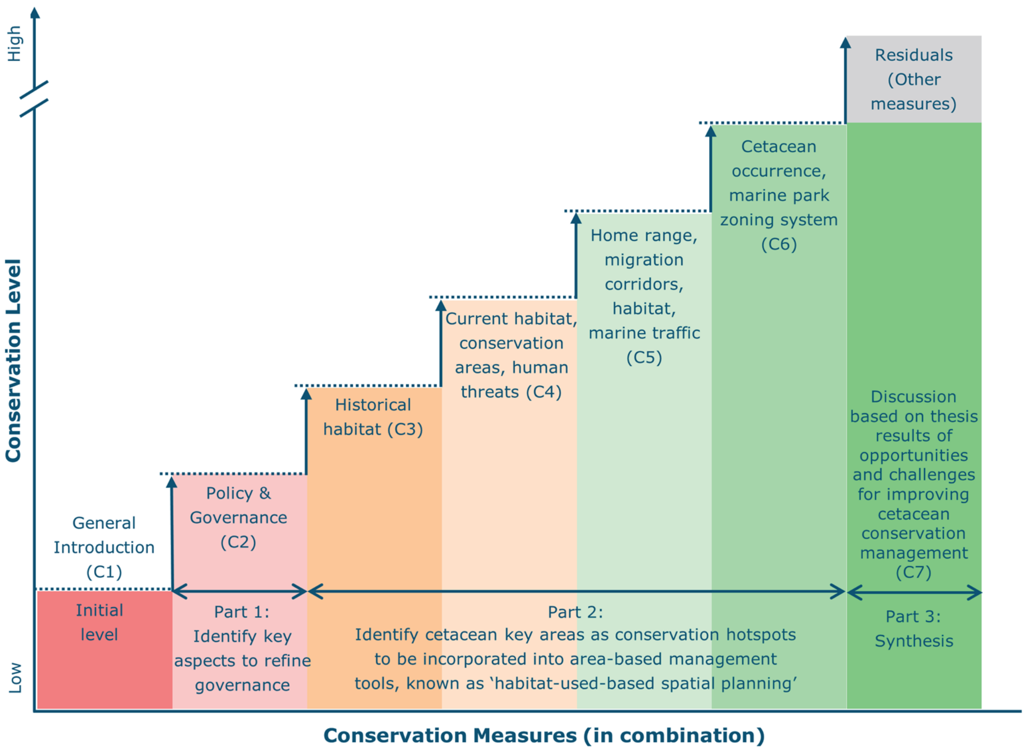

Fig. 7.1. Schematic representation of the contribution of the thesis result chapters (C) to advance conservation management of cetaceans in Indonesia. Additional measures can further improve the level of conservation. The order of the Chapters C2-C6 is interchangeable.

7.1. Main governance challenges and ways forward for cetacean conservation management

7.1.1. Mandates and what is lacking

The Indonesian marine mammal protection and governance currently consists of 7 different policy approaches that are either species-specific, site-specific or concern other policies (Chapter 2, Fig. 2.5). The species-specific aspects designate marine mammals as protected species, requiring the sustainable use of marine mammals with bans on hunting, killing or trading them, and mandating measures for reducing bycatch. Site-specific policies include encouraging MPA establishment and marine pollution management. The other policies include promoting regional and international collaborations and developing action plans for marine mammal conservation. The governance, however, does not include regulations on traditional whale hunting, underwater noise pollution, a code of conduct for marine mammal tourism, and standards for ex-situ conservation, thus hampering effective species conservation management. It is advised that Indonesia includes such regulations into the current legal framework to strengthen it. In addition, it is hard to quantify the effectiveness of the current regulations as the level of the implementation and enforcement is not known and there is lack of data availability on the cetacean population statuses.

7.1.2. Mandates and compliance

The governance review (Chapter 2) revealed that at several instances, wordings used in the regulations gives room for multiple subjective interpretations. For example, marine mammals are considered 'fish' in some regulations, and labelling marine mammals as such may lead to the misconception that those species are available for harvesting. Furthermore, imprecise policy objectives and unclear mandates result in insufficient guidance for implementation. Where the regulations do not provide clear guidelines for operationalisation and only mention general words without complete definition or explanation, most stakeholders apply their own interpretations. Such confusion occurs e.g., in the case of the national guidance on incorporation of migratory corridors in an MSP (also in MPAs) that is implemented quite differently in the provincial regulations: some regulations use protected zones, some have no specific allocations, and some only use indicative lines. Whether or not a national guideline can be applied and complied successfully by lower level governments depends on the clear articulation of regulations in the implementation process. It is important that a policy mandate includes detailed implementation guidelines and clear practical actions and avoid the vagueness of regulation documents that would hamper implementation.

The governance review also revealed significant institutional shifts of marine mammal protection governance from a ministry responsible for the general agricultural domain, to one responsible for forestry and environmental spheres, then finally to a more dedicated ministry focusing on marine management explicitly covering marine mammal governance. These changes reflect the increasing priorities of the government and the more clearly articulated responsibilities for marine biota conservation. This effort is considered an improvement, since establishment of new institutions was required to handle specific tasks that previously were not well delivered. The marine mammal protection and wider marine management could still be further improved by resolving the inefficient and ineffective functioning of institutions at mainly national (ministerial) level. For instance, the changes in institutional arrangements did not resolve yet the functional overlap and responsibility dualism between the Ministry of Environment and Forestry (MEF) and Ministry of Marine Affairs and Fisheries (MMAF), even with the establishment of a new Coordinating Ministry. Each ministry still claims that the mandate to manage marine conservation areas and marine biota is under its institution. It remains unclear whether the shift in governance indeed will have real positive effects on the marine ecosystem protection. These changes have implications for enabling and constraining effective marine mammal and area-based management. The conflicting viewpoints need to be resolved immediately, for it hampers effective working dynamics at the grass root level, for example, by frustrating DNA sampling procedures during research and marine mammal stranding follow-up.

Not only between regulations, also between institutions coordination of activities and mandates are important for marine mammal and area-based management. This, however, is not yet well organised in Indonesia. Sector-based policy implementation is characterised by procedural and not relational coordination. For instance, the regulations for wildlife management and marine conservation areas are governed by different sets of authorities and regulations. Marine (mammal) governance in Indonesia is characterised by institutional ambiguity with uncertainty and confusion about authority. The effective management suffers from fragmentation of governance, where several policies exist, each of them is managed by a specific agency at different levels of governance with no mechanisms in place for the coordination. This is why it took almost two decades to move the responsibility over 7 marine national parks from the MEF to MMAF. There still is no successful agreement and as a consequence the deadlock situation is still not resolved. Building bridges among sectors is urgently needed to resolve functional overlaps and responsibility dualism among institutions. Institutions with overlapping mandates should working together towards a common goal, developing mechanisms for cross-institutional cooperation to optimise the ministries' tasks. A ministry can opt to transfer authority to another ministry in order to achieve policy goals, which would not so much weaken the role of the first ministry, but strengthen the development and implementation of the ministry's effectiveness.

7.1.3. International agreements and collaborations

Although all marine mammal species are protected under national regulations, Indonesia has no legal act regulating hunting practice that targets vulnerable species such as sperm whale [65]. As in Lamalera, local communities have been practising whale hunting for generations, the Indonesian government is not yet a full member of the International Whaling Commission (IWC) and the Convention on Migratory Species (CMS) (Chapter 2). As traditional knowledge and practices such as aboriginal whale hunting are nowadays acknowledged by global treaties (e.g., Convention on Biological Diversity (CBD) and International Convention for the Regulation of Whaling (ICRW)), these local practises should be integrated into species and area-based management. The integration of such local practices will support the goals and objectives of both the conservation management and the needs of the people as has been arranged in several national legislations of other countries [513–515]. The sustainability of traditional whale hunting remains a concern, hence the sustainability of that practice should be assessed. This assessment includes determining whether the practices are still under the 'aboriginal' category and individual taking is not exceeding Potential Biological Removal thresholds [55]. Based on such an assessment, the government can take a follow up in mediating the observed conflicting practices as a joint problem solving effort.

In order to strengthen the conservation of migratory species, the Indonesian government should seriously consider becoming a full member of the IWC and CMS. Due to the highly mobile nature of marine mammals, the management of such species can only be effectively organised and enforced at an international level. Both global treaties are widely recognised as an effective conservation agreement with broad membership. The IWC can support the assessment of traditional whale hunting sustainability in Indonesia and other whale-related aspects, including management of whale watching, ship strikes, marine noise, chemical pollution, marine debris, cetacean conservation, and climate change issues [234]. The CMS can support Indonesia in research and management of marine mammals and facilitate regional cooperation with other members such as Australia that performs broad studies on marine mammals [55]. Countries outside the conventions (non-parties) reduce the effectiveness of the regulations, since both conventions are only as effective as its coverage. By joining both treaties, Indonesia would improve the coverage and effectiveness and in doing so would be welcomed by the wider international community. Potential assistance such as financial or technical support can also be provided by their Secretariats. The global treaties require a country that seriously wish to join, to formally affirm its intent to become bound by the treaties, and to deposit an appropriate legal instrument defined by its national law through the ratification of the treaty in the national authority. In fact, Indonesia has recently stipulated a ministerial regulation that forces the establishment of MPA networks for protecting endangered and migratory species within regional and global scales (MMAF Regulation No.13/2014 art. 12). With the same interests between national and global policies, the process of joining both conventions will be straightforward.

Another way forward to advance cetacean conservation in Indonesia is by optimising the government's roles in the current more regional collaborations that could be multi-national. The analysis in Chapter 2 showed that the existing collaborations are not yet optimised for marine mammal conservation management which is considered a peripheral issue among other 'hot' issues arranged in the regional collaborations. For instance, the Coral Triangle Initiative (CTI) only has 1 goal related to endangered species within its Regional Plan of Action (RPOA) and that does not focus on marine mammal protection. A review commissioned by the Southeast Asian Fisheries Development Centre of the Association of Southeast Asian Nations (SEAFDEC-ASEAN) was performed on cetacean studies in SE Asian waters. This, however, did not result in follow up actions to improve cetacean conservation management. Targeted actions through project-based initiatives could prove effective to put marine mammals on the map through 'marine megafauna' or area-based management approaches that would strengthen the efforts within current regional cooperation. Such effort could be initiated to conserve and manage migratory species that occur in more than one bordering country's jurisdiction such as the CTI members and Australia. Chapter 5 for instance, showed a high level of connectivity between Western Australia and Indonesian Seas for pygmy blue whale migration. The financial and organisational capacity to establish and enforce multi-national, regional or international collaborations among countries sharing the same marine system is currently, however, limited. An important bottleneck is the varying capacity and willingness of states to collaborate, and the lack of mechanisms to enforce compliance.

7.1.4. Dedicated MPAs for marine mammals

Although MPAs and MPA networks have proven very effective to protect top predators like marine mammals in other parts of the world [12,98], only 2 of the current 196 designated MPAs in Indonesia are dedicated to protecting marine mammals [516]. As this is not enough for effective marine mammal protection (Chapter 2), it is recommended to establish more MPAs in Indonesia that are specifically designed for these migratory species. Several current MPAs (e.g., Komodo, Wakatobi, Bunaken NPs) actually include some marine mammal habitats (Chapters 3-6), but the MPA designations do not specifically consider the key areas of these species. The current zoning system could be adapted to accommodate migratory species' ecological needs as well, enhancing the value of these MPAs. A challenge is to determine the sizes and number of MPAs that would be enough. This could be based on policy driven goals in terms of a certain percentage of the country's area that is to be conserved, e.g., 10% as suggested by the CBD. Such targets, however, mostly lack a biological basis [517]. The plausible percentages of areas for evidence-based targets are around three times higher than those suggested in policy-driven targets [517]. Achieving and maintaining at least 10% of the country's critical habitats in protected areas is, however, still a challenge for Indonesia that at the present time only 7.5% is achieved [516], so the country does not meet the CBD's recommended percentage.

Effective conservation management for managing cetacean migratory species remains a concern for Indonesia. As discussed above, the current management system still is sub-optimal to achieve the required and desired goals in conserving migratory species. To resolve these management challenges, initiatives should be developed, including area-based management in coherence with other measures. It is obvious that this requires good knowledge of the ecology and population distribution of the cetacean species.

7.2. Main challenges and ways to fill the knowledge gaps in cetacean species distribution

7.2.1. What are the knowledge gaps?

Management and governance of migratory species such as cetaceans should depend more than is currently the case on scientific information about their key habitats over time and space. Cetaceans are difficult to observe in the wild and demand costly logistics for dedicated collection of their data. As a consequence, the cetacean distribution is still poorly known and understood, and this information challenge hinders their conservation management in Indonesia. For instance, the incorporation of critical habitats and migratory corridors of marine biota into area-based management tools (MPAs and MSP) is hampered by the lack of such data. This thesis presented an approach to address this knowledge gap and increase the understanding of the diverse assemblage of cetacean species in these previously unstudied regions. In Chapters 3-6, different approaches have been applied to fill the knowledge gaps in cetacean species distribution. Clearly, spatial distributions are species specific and dynamic over time and space. Species vary widely in their habitat requirements e.g., the area required for large whales such as sperm whale (Chapter 3) and pygmy blue whale (Chapter 5) is much larger than for a smaller Irrawaddy dolphin (Chapter 4). The minimal habitats required to maintain ecologically or evolutionarily viable populations may vary by orders of magnitude [393,518]. Also, cetacean spatial and temporal distributions are not homogeneous entities as some may be quite mobile and some other rather sedentary depending on life-stage related traits. Spatial and temporal occurrence as well as the annual variability and migrations are driven by e.g., changes in oceanographic conditions or location-specific high food abundance [27,285,519] which may only persist for a period of a few days up to several weeks [421].

If the cetacean distribution is known, this should be taken into account when optimising conservation management design. If their distribution is unknown or the scale of the target species' movement is too large to include in individual MPAs, they could be protected within a network of MPAs in combination with other management approaches. MPAs should be designed to allow for safe movement of the species among protected habitats. Knowing the dynamic nature of the species and their habitats, thus there is no one-size-fits-all spatial management solution for these migratory species.

7.2.2. Identified species distributions related to species traits

A great heterogeneity in the distribution was found among species and within species among different locations (Chapters 4 and 6). The results do, however, emphasise the importance of coastal areas and insular-reef complexity for several cetacean species, since both areas represent high productivity and upwelling-modified waters (Chapter 4). The observed habitat segregation among different species avoids resource competition and represents intraspecific resource partitioning. The species feed on different prey distributed over different locations for which they use different foraging strategies [520]. For instance, sperm whale feed on deep squid [284], therefore they are found much more in deep waters around continental slopes compared to smaller bottlenose dolphin that mainly use shallower shelves (Chapter 6). Habitat segregation between small and large-sized cetacean species also became apparent (Chapters 4 and 6) and was related to depth gradients [458]. Within the same species, the habitat preferences may differ depending on the area that the animals are in. This depends on the different combination of environmental variables and the life stage or stage of migration that the animals are in. Also, animals can be opportunistic about the habitats they live in, depending on resource availability. This is the case of the sperm whale which was found in different areas with different characteristics (Chapter 4) [298].

While disparity among species distributions can be expected, also distribution overlaps can be found when species have the same dietary preferences or use the same environmental characteristics [400,423,521]. Chapter 6 shows that bottlenose and spinner dolphins occurred in the same habitats characterised by shallower waters, and depth often was the main determinant for species co-occurrences [520]. Since Indonesia is a conjunction between the Indian and Pacific Oceans [75], the co-occurrence of different species representing both habitats is to be expected and may explain the high diversity of cetaceans in the region. Overlapping habitats among species may stimulate niche specialisation as well as potential interspecies competition. Areas with high overlapping cetacean habitats are candidates for conservation priority areas [279], but it is important to realise that protection of additional areas may be crucial for some specific species e.g., estuarine areas for Irrawaddy dolphins.

Cetaceans differ highly in traits such as food preferences, body surface-volume ratio and physiological adaptations for deep diving [266] and these species traits were clearly reflected in the model outputs (Chapters 3 and 4). For instance, sperm and pilot whales have lower energetic costs and are able to forage deeper than most smaller delphinid species and therefore can harness deeper prey along the continental slope than species with higher energetic costs and shallower diving abilities [266]. Cosmopolitan species like the bottlenose dolphin prefer coastal areas with shallower feeding grounds that often hold complex and rich food webs [329]. All these species traits fit the population distributions that our models predicted showing the robustness of these models in providing ecological insight as well as opportunities for practical management application.

Oceanographic and topographic features clearly define cetacean habitats in the habitat modelling (Chapters 3-5). The predicted habitat of sperm whale in the past were characterised by distance to coast, distance to deep waters isobaths, and submarine key features (Chapter 3). The study also revealed absence of seasonal differences in sperm whale distribution in four areas in the eastern part of Indonesia, while noticeable seasonal differences were identified in other areas. The sperm whale historical distribution study also illustrates to what extent we currently are studying a shifting baseline in species distribution caused by historical exploitation (outlined in Chapter 3). Sperm whales were intensively hunted for almost two centuries for sperm oil [282], and the recovery of the species is still limited since then [199]. Comparing historical sperm whale distribution maps (Chapter 3) to the current ones (Chapter 4) provides insight in the great differences in species distribution and density, although it is important to note that the currently available data are restricted to more coastal areas. Historical data can help identify potential key habitat and migration lanes, so even when currently a species is almost absent, we can already find out where they potentially would thrive. Such areas are candidates for protection in MPAs.

Areas rich in species were mainly related to coastal areas or insular-reef complexity with elevated Chl-a concentration and sea surface temperature (SST) (Chapter 4). These topographic and oceanographic combinations represent high productivity and upwelling-modified waters [185,279]. Both factors affect the distribution of nutrients and suspended material, and therefore play important roles in determining biomass development, food web structures and species distributions [436]. The SST and distance to shelf were the most important variables in determining pygmy blue whale's (PBW) habitats, and to lesser extent, slope and Chl-a concentration. Shifts in SST and the presence of localised productivity areas along migratory corridors are presumed to drive and support the PBW migration from Australia to Indonesia (Chapter 5). From an energetics perspective (V. Andrew-Goff pers. comm.), it is likely that the whales use patchy but highly productive areas with dense prey aggregations [193,431]. This phenomenon was also reported in the Azores, where blue whales interrupt their migration to exploit localised high productivity areas [214]. For PBW, however, further investigation is needed to confirm this habitat use during migration. Kahn [522] assumed that the whales feed in Indonesian waters based on the analysis of diving profiles from satellite tags.

The cetacean key areas identified in this thesis include suitable habitats, core-use areas, migration corridors (Chapters 3-6) and the potential seasonal variability in their use (Chapters 3, 5, 6). This information is a valuable basis to direct future monitoring programmes to confirm the modelling outcomes. For instance, with limited resources we have, we can already pinpoint a study area candidate for dedicated cetacean monitoring projects in Indonesia. Once the temporal and spatial locations of the focal species' key habitats are known, these areas should be protected in permanent or seasonal MPAs.

7.2.3. Used datasets and multiple method approaches

The value of multi-data and multi-method approaches: Bridging the gaps

This thesis demonstrated the value of applying multi-method and multi-dataset approaches in providing a more comprehensive picture on the cetacean distribution in areas with unprecedented studies, therefore help bridge the knowledge gaps. Conservation management needs more applicable information rather than cetacean species lists and rough abundance estimates as basis where to allocate MPAs that cover the hotspots of target species [329]. In case of limited availability of systematically collected data, applying a combination of methods and datasets is the only available option. This thesis exhibits how multi-method and multi-dataset approaches can provide useful and novel information for previously unstudied regions that can aid cetacean conservation management efforts. Combining different methods offers the opportunity to analyse cetacean habitat and relative abundance estimates over time, and compensate the limitations of each technique by the others. None of the methods or datasets are essentially better than the others as each covers distinct time periods and areas and provides different specific information.

Using multi-methods enables the production of more coherent results, because each different method triangulates and complements the results from other methods [523]. For example, habitat modelling used in Chapters 3-5 can identify key conservation hotspots for cetaceans, while a home range analysis (Chapter 5) was applied to fully capture the potential for improved knowledge on pygmy blue whale's ecology. The simple mapping technique in Chapter 6 also further complements the results of Chapters 3-5, and together can support area-based management. The use of multi-methods can also address the limitations or disadvantages of certain methods [523]. For instance, the limitations of a simple mapping method in visualising occurrence points of cetacean species in Chapter 6 has been cancelled out by using more complex habitat modelling in Chapters 3-5 that links the cetacean presence data with environmental variables that determine species habitat preferences. The historical models of sperm whale that only used topographic variables (Chapter 3) can be compensated by the models that use current topographic-oceanographic variables (Chapter 4). Another example is the limitation of narrow time-window of current sperm whale presence data (Chapter 4) can be compensated by using a large number of sperm whale historical data (Chapter 3). Similarly, limited spatial scales in habitat modelling study in Chapter 4 can be compensated by large scale habitat modelling from Chapters 3 and 5.

In addition, the multiple datasets used complement each other, although as is to be expected when using information from different sources, the sample sizes vary greatly among locations and time periods. The historical whaling data (Chapter 3) and telemetry data (Chapter 5) enabled modelling sperm whale and pygmy blue whale distributions in different seasons. The current data (Chapter 4) contributed to cetacean distribution models for more diverse (15) species. The value of such an approach combining multiple datasets was also reported in previous modelling studies [110,312]. The combination of platforms of opportunity and incidental sighting data provided cetacean occurrence patterns in an unstudied tropical marine park (Chapter 6). Data from platforms of opportunity have also been successfully applied in other cetacean studies [209,317,524].

The feasibility of using data from cost-effective surveys

Performing systematic surveys can be prohibitively costly [13,208–210], because they generally involve dedicated vessels and trained observers, therefore platforms of opportunity were used as an available alternative in this thesis (Chapters 6). The disadvantage of using platforms of opportunity is that they usually have limited and non-systematic coverage. However, the platforms of opportunity data from Wakatobi NP provided samples of the same area collected repeatedly allowing to study cetacean occurrence over time as also reported by other studies [e.g., 43]. With stringent data filtering (i.e., by using a sub-sample of the dedicated fishing monitoring data, Chapter 6), valuable information was obtained. This includes information on cetacean species occurrence and a first indication of the cetacean population status and relative density. The analysis revealed that sighting frequency in Wakatobi NP varied annually and monthly for small and large cetaceans. Reduced efforts in the rough-weather months [452] and at the end of the monitoring programmes affected the sighting frequency of cetaceans (Chapter 6). The probability of cetacean sightings is affected by several factors [126,461,499] and the impact of known factors was analysed. Our analysis showed that there was no correlation between season and distance between observers and animals with the prevalence of unidentified dolphins or whales. Instead, a significant determinant for the prevalence of unidentified cetaceans was the number of animals per group per sighting. It means that the smaller the number of animals per group, the more likely the species was reported unidentified. With only a few individuals being sighted, it was harder to identify the species.

Even with data from cost-effective platforms of opportunity and incidental sightings, unstudied areas can be indicated as important areas for cetaceans. For instance, Wakatobi was found to be a potential nursery or calving ground for cetaceans (Chapter 6). In addition, overlap between cetacean hotspots and intensive fishing activities was revealed. Potential competition for resources between cetaceans and fisheries is a globally recurring management issue [56,190]. This may involve reduced prey availability for cetaceans due to (over-) fishing and vice versa reduced catches by fisheries due to cetacean predation. Investigating whether competition for resources exists is complicated by the lack of research data. Cetacean occurrence in the use-zones of a marine park reflects potential conflicts and conservation issues (Chapter 6) and unveiled mismatches in the current zoning system. These findings are important input for refining future marine park rezoning efforts.

Low-cost approaches for under-studied areas

Indonesia is very rich in cetacean diversity and density, but also is among the most poorly studied regions for cetaceans. Since many cetaceans in the region are exposed to local threats such as bycatch, habitat degradation, and direct capture, they are in urgent need of protection. Systematic survey efforts in some areas within Indonesian waters have been limited [195,460], therefore even general data on species occurrence are lacking. To address this lack of data in the light of emerging conservation needs, this thesis study provided novel information on cetacean distribution, adding new insights to currently limited knowledge on cetacean status in the region. This information includes sperm whale distribution in the past (Chapter 3), distribution of 15 selected species in 7 ecoregions or seascapes (Chapter 4), pygmy blue whale's habitats, migratory corridors and core-use areas (Chapter 5), and spatio-temporal occurrence patterns of four most sighted cetacean species in Wakatobi NP (Chapter 6). A relative abundance estimate was successfully calculated using sighting frequency from platforms of opportunity data. This new information could only be provided by applying multiple complementary methods and available underused datasets.

Low-cost survey methods such as platforms of opportunity can be used to better understand the fine-scale spatial and temporal distribution of cetaceans. In Chapter 6, such a method was applied to explore how the four most sighted cetacean species use the different habitats in a marine park. Actually, this fine-scale study provided a detailed insight into the occurrence patterns of the cetaceans that could not have been obtained with single large-scale surveys. It was also shown that the presence of those cetaceans was linked to depth and that different species used different core areas or hotspots. A fairly consistent survey design over a long-term period is imperative in deriving robust data providing new insights into the fine-scale habitat preferences of the species.

The reliability of habitat models and non-systematic survey data

To assess the reliability of habitat models used in this study, the results among different chapters that used the same models and/or from other studies were compared. For instance, current sperm whale distribution (Chapter 4) predicted by the Maxent model also matched with that predicted independently for the historical period using the same model (Chapter 3), which supports the reliability of the model. Also, the predicted habitats for 7 cetacean species from this study (Chapter 4) are in agreement with the habitats of those species reported by other studies in the overlapping regions [e.g., 331]. Even the PBW's suitable habitats (Chapter 5) that were identified in the Southern Java Sea without presence data available could be confirmed by a recent study by Möller et al. [525] that did include presence data, corroborating the models used in this thesis. These findings indeed reflect the reliability of the used models.

Regarding the reliability of using non-systematic survey data, the estimated relative abundance (i.e., sighting frequency) for small and large cetaceans from platforms of opportunity used in Chapter 6 closely matched the results from a study using a systematic survey in the neighbouring region [460]. The sighting frequency in Wakatobi was about tenfold lower for large cetaceans than for small cetaceans (Chapter 6) which is in accordance with results from North Papua for large vs small cetaceans [460]. This reflects the reliability of using non-systematic survey data for relative abundance estimates, although due to differences in survey platforms, methods, experience of observers, data from different studies may not be directly comparable and a vigilance is needed, as is discussed in more detail in Chapter 6.

7.2.4. Observed overlap of cetacean key areas with human activities

Integration of threat data and cetacean key areas into area-based management tools such as MPAs and MSP adds another level of information for species conservation management. Chapters 4 and 5 revealed that cetacean key habitats overlap with anthropogenic threats such as oil-gas contract areas and marine traffic. Current economic government policies encourage the expansion of oil-gas exploration and production throughout Indonesia, including locations identified as important cetacean habitats and potential migratory corridors. Clear examples were found in the NE Borneo Seascape, SE Sulawesi Seascape, Lesser Sunda Ecoregion, Wakatobi, Bird's Head Seascape, and in the Fakfak Seascape (Chapter 4). Oil-gas exploration activities can cause extreme noise disturbance to cetaceans from seismic surveys [46,47] that may displace both cetaceans [251] and their prey [526], and even lead to strandings [251,527]. Currently, Indonesia has no regulation on underwater noise including from seismic activities (Chapter 2), meaning seismic vessels operating in Indonesia are not legally required to comply with international standards to reduce impacts on cetaceans. The Lesser Sunda and Sunda Strait have more dense shipping lanes (Chapters 4 and 5) indicating that cetaceans face increasing risk of cetacean-vessel collisions, acoustic disturbance that can mask echolocation signals, impaired foraging and displacement from core habitats [43–45,528]. Although some cetacean suitable habitats exist close to the designated marine traffic lanes, Indonesia has not designated any sensitive areas as protected cetacean habitat (Chapter 4). Chapter 6 documented interactions between cetaceans and fisheries activities that can cause mortality, bycatch, entanglement, drowning, ship collision, prey depletion, and eventually population decline [32,38,39,41,42,240,491]. The information about anthropogenic threats is important in MSP and designating MPAs, since anthropogenic threats decrease ecosystem health, productivity and resilience to other stressors like climate change, adversely affecting many species and severely undermining the long-term sustainability of marine resources and the ecosystem services they provide [529]. Identification of the main threats is a necessary step to optimise measures to mitigate them.

This study also revealed that the actual whale migration routes deviate from the legal designated migration lanes in Indonesia (Chapter 5). The observed migration routes in the Wetar Strait, Timor Trough and Molucca Sea are not currently included in the designated migration lanes in Indonesia. Protecting migration corridors of large mobile animals is important to maintain gene flow and biodiversity as basis for healthy cetacean population conservation [125,413,416].

7.3. Area-based approaches (MSP, MPAs) for cetacean conservation management

The increasing competition among the growing number of users and activities in the marine space requires area-based management such as MSP, with MPAs as one of its components, as an integrated tool for managing and synergising multiple human activities and nature conservation. It has been widely advocated to base this on an ecosystem approach [89,530]. Yet, marine spatial allocations mainly pave the way for human (socioeconomic) activities [531]. Partially due to the lack of ecological knowledge, spatial consideration of key habitats and corridors of migratory species such as cetaceans have been overlooked in Indonesia. The following will discuss how area-based approaches (MSP, MPAs) can support cetacean conservation management.

To date, 196 national and local government MPAs are established in Indonesia, covering an area of 23.15 million ha and accounts for 7.5% of the country’s territorial waters [516]. In 2010 at the CBD-10 meeting in Nagoya, Indonesia proposed to allocate 10% area of its territorial waters (31 million out of 310 million hectares) as MPAs. If all existing MPAs and key areas identified from this study (Chapters 3-6) would be combined, the 10% target will be achieved. The key areas include sperm whale habitat as become apparent from the past (Chapter 3) and other important cetacean habitats that are located outside existing MPAs and waters beyond 12 nm from the coastline (i.e., outside the provincial MSP jurisdiction and territorial waters) (Chapter 4), and key habitats of pygmy blue whale in the high seas (Chapter 5). The Government of Indonesia recently announced the ambition to achieve the new target of 30 million hectares of MPAs by 2030 [532].

In addition, cetacean habitats and migratory corridors can provide a potential platform for MPA networks that the government is eager to achieve but difficult to develop due to the lack of information. Currently, no MPA networks exist and the existing MPAs in Indonesia are mainly located in coastal areas. The identified key areas from this study can also contribute to represent deep-sea priority areas which are not yet covered in the previous conservation efforts. These areas include near-shore-yet-deep-sea migration corridors for large whales, high productivity upwelling sites that provide foraging habitats for large whales and oceanic dolphins, and presumed breeding and calving areas for large whales in the wider Lesser Sunda, Bird's Head Seascape and the Banda Sea. The results this thesis provides can support cetacean protection management, help to refine the zoning design of MSP and to designate potential new MPAs and MPA networks. To optimise cetacean protection, it is advisable to add the key areas that are currently not yet protected through establishment of larger new MPAs, since the larger MPAs are reported to be more beneficial for protecting migratory species [12,434].

7.3.1. Habitat-use-based spatial planning: promising approach & challenges

In the design stage of area-based management tools (MPAs and MSP), managers are challenged by global agreements to incorporate solutions for the increased ecological concerns through the development of ecosystem based approaches. The approaches require involvement of ecological consequences already in the planning stages. In this regard, a habitat-use-based spatial planning approach gets its momentum. Habitat-use-based spatial planning can enable ecosystem based approaches in area-based management tool establishment, incorporating cetacean key habitats and migratory corridors. Using species distribution models and home range analysis such as those presented in this thesis (Chapters 3-5) and spatio-temporal occurrence patterns (Chapter 6) provides useful input to identify priority areas to optimise the protection of cetaceans. The identified key areas (i.e., suitable habitats, core-use areas, migration corridors and their seasonal variability) from this study were also acknowledged as Important Marine Mammal Areas (IMMAs) by the

IUCN Marine Mammal Protected Area Task Force [350]. In Indonesia, the ecosystem based approach has been supportive in the transformation of MSP mostly focussing on human uses towards ecology-inclusive planning by incorporating key habitats of migratory species (Chapter 1, Box 1.1). This requires a new mindset of actors involved in marine management, from a focus on plotting human activities in marine spaces to balancing these with ecological needs. Potential challenges of such an approach will be elaborated below.

Will the MPAs and MSP provide sufficient (spatial) protection for cetaceans?

Measuring the effective conservation of migratory species within area-based management is challenging. It is obvious from the information provided in this thesis, that the current MPAs and MSP designs in Indonesia are too limited to provide effective protection for highly mobile cetaceans (Chapters 4-6), although they are maybe beneficial for sessile species or species with limited movement (Chapter 6). The only (partial) protection provided for cetaceans in Indonesia results from a limited number of small MPAs as well as conservation zones and migration corridors within MSP. Although other MPAs in Indonesia were not examined, those small reserves likely also provide limited advantage for cetaceans, as MPAs in Indonesia were predominantly designed to conserve more sessile ecosystems and to support sustainable local fisheries.

Movement patterns of cetacean species is an important factor to consider when designing MPAs and MSP with sizable no-take zones. Where movement patterns and home ranges of target species are known, as in Chapter 5, this information can be used to define optimal size, shape and location of core zones of MPAs to optimise conservation benefits. When cetaceans leave MPAs, however, they become vulnerable to anthropogenic threats such as fishing pressure [12]. For viable cetacean populations, Indonesian policy should prioritise enlarging the existing MPAs by linking current MPAs into a smartly designed cetacean habitat network. MPA networks can deliver additional benefits by acting as mutually replenishing networks to facilitate recovery after disturbances [529]. However, it may not be possible to establish MPAs large enough to encompass all of cetacean species' movement patterns. In addition, even when such MPAs are formally established, maintaining their ecological integrity has proven to be a challenge. For instance, "paper parks", protected areas established on paper but not enforced as such, exist in many countries including Indonesia [1]. The required increased country's management expenses and enforcement burdens are a true challenge in the establishment of effective larger MPAs.

Could multi-functional MSP and MPA zoning systems be effective for cetacean conservation?

MSP in Indonesia is a mapping process that consists of two components: a coastal zoning map of the 12 nm area of coastline and small islands (or RZWP3K), as well as a National MSP of the marine areas from 12 to 200 nm outer seas and all inner seas [349,533]. Four different zones are mandated in the mapping process: conservation areas, sea lanes (including migratory species' corridors), specific national strategic areas (for a 'strategic project') and public usage areas. Together, these components will fully map the entire country's EEZ and serve as the basis for allocating permits to different users. Provincial governments have a planning authorisation for sea space under 12 nm from the coastline as a result of decentralisation policy. In contrast with this administrative boundary, conservation of migratory species, however, needs to be set based on its expanding spatial scale, requiring another type of governance or management. Such management entails an ability to govern through non-territory-based regulations, unlike the conventional conservation which relied on territory-based regulations. Hence, ecological boundaries seem to be more appropriate for ecological sound management of migratory species. The governance of this complex and mobile activity cannot rely on traditional governance arrangements using territory-bound regulation (as in Chapter 5). Since the MSP in Indonesia has only just started, the waters beyond 12 nm is not yet a zoned area, although the legal framework for it is already mentioned in some regulation documents (see Box 1.1 in Chapter 1). The ecological boundary appears to be more applicable for migratory species conservation in the waters beyond 12 nm.

Building a more adaptive MSP can be facilitated through a stepwise process. The emergence of habitat-use-based spatial planning does not mean existing MSP will totally disappear or be useless. Instead, the new planning will complement and refine the existing one. There is an urgent need for information revealed from this study (i.e., critical habitats and migratory corridors) to be proposed for future spatial consideration, as zoning of all MPAs and MSP in Indonesia is scheduled for review every 5 years. During the review process, it is crucial to ensure that the marine planning process includes the conservation needs of marine migratory species. Worldwide, protecting important habitats of top marine migratory species is a priority issue for MSP development [98].

Serious challenges for future cetacean conservation management emerge. For instance, what to decide when cetacean key habitats overlap with high-profit industries that may negatively impact marine habitats and species? To illustrate, in Balikpapan Bay, Irrawaddy dolphin habitats are also used for coal transport shipping (Chapter 4). Or what to do where cetacean habitats overlap with fisheries, oil-gas mining areas and marine traffic such as in Lesser Sunda (Chapters 4 and 5). Important cetacean migration corridors in Lesser Sunda also are a traditional fishing area [384].

Similarly, cetacean habitats in Wakatobi NP are also use-zones where tourism and traditional fishing activities are allowed (Chapter 6). These overlaps concern locations where cetaceans aggregate and become vulnerable to human activities. Potential loss of productive fishing grounds [534] also make local fishermen disagree with MPA establishment. In such highly competed areas, the options for cetacean conservation via MPAs may be limited, so additional management options should be sought.

Area-based management usually comprises mixed objectives, ranging from purely conservation purposes to accommodating human uses including fishing, tourism and shipping. This aims to optimise marine space uses, for example making use of the fact that migratory species do not year-round occur at a location. Mainly in the season that the density of animals increases, the potential conflicts such as bycatch, disturbances and ship collisions occur. The multi-function zoning systems of MPAs and MSP could become relevant for cetacean conservation, if those area-based management tools are optimised for a combination of activities. This could be completely integrated activities or separated activities in space or time. Several possible combinations have been reported, including between: nature conservation through MPAs and tourism [535,536], nature conservation through MPAs and fisheries management [537,538], and nature conservation and scientific research [539]. These possible synergies can only be realised, however, through habitat-use-based spatial planning.

For most species, the distribution is generally patchy and some areas are more densely occupied than others. While some cetaceans may exhibit high site fidelity and seasonal movements between their aggregation sites (Chapters 4 and 6), some are highly migratory and move thousands of kilometres between presumed breeding and feeding areas both in Indonesia and bordering countries (Chapters 3 and 5). Migratory species typically range over vast areas of ocean, but often also concentrate in smaller, localised regions (hotspots), for periods of time. These aggregation areas should be protected in permanent or seasonal MPAs and MPA networks at the national scale in Indonesia, or transboundary MPAs or MPA networks with adjacent countries.

7.3.2. How to integrate migratory species key areas into area-based management?

The Indonesian government has been sub-optimal in accommodating migratory species habitats and corridors in the design of MPAs and MSP. Their spatial designs draw heavily on speculations due to the lack of data, while having to fulfil the obligation from the regulations. This speculative accommodation instead of science-based argumentation may notably underestimate the real key habitats and migration corridors. As it is indicative, migration lanes also are not so detailed either in shape, location, or size. This thesis provides a first planning approach based on empirical results which delivers sufficiently robust insights to improve the basis of decision making. Conservation management should be based on the best available information and mapping of the distribution of species to make it an evidence-based approach and successful [517].

This thesis proposes some strategies based on the results of this study for incorporating migratory species' key areas into the Indonesian area based management such as MPAs and MSP. In Fig. 7.2, the strategies are depicted as follows: (i) consider sperm whale habitats in the past (Chapter 3), focusing on core habitats that persists over seasons; (ii) expand existing MPAs that are located near the newly identified cetacean key habitats (Chapters 3-6); (iii) prioritise the habitats that are used by more than one species (see the combined species maps in Chapter 4); (iv) develop new MPAs that include the deep-water habitats to represent previously these neglected key habitats (Chapters 3-6); (v) take cetacean key habitats (Chapter 3-6) into account to guide MPA networks establishment; (vi) incorporate cetacean key habitats within MSP's conservation zones during the review process; and (vii) accommodate cetacean key habitats (Chapters 3-6) in National MSP of the marine areas from 12 to 200 nm outer seas and all inner seas. Additional mitigation measures may be needed for managing cetacean key habitats that overlap with human activities. All these strategies can eventually cover the cetacean habitats and migratory corridors identified in this study, hence can provide spatial protection to optimise cetacean conservation management.

7.3.3. Supplementing habitat-use based spatial planning with other approaches

Area-based management cannot always provide a stand-alone solution for cetacean conservation (Fig. 7.1). In several situations, these tools may be difficult or impossible to establish e.g., because of the conflicts with other marine users' and disagreements [540]. The emerging demands for cetacean protection trigger concerns over the reduction of economic opportunities for human users of the marine realm. Therefore, area-based management may need to be combined with additional pragmatic measures to achieve a desired level of cetacean protection to address important threats [1]. For instance, restrictions on fisheries activities using destructive gears in the location where cetaceans aggregate can provide increased protection for cetaceans. For example, in Lesser Sunda, cetacean conservation areas are integrated with traditional fishing areas, allowing fishermen to harvest in the productive areas while incorporating cetacean protection measures [384]. Other countries successfully applied seasonal closures during migration and breeding seasons and ship rerouting [310,347]. Further conservation approaches include the regulation of international cetacean trade and hunting and promotion of cetacean-friendly ecotourism [1]. Other considerations that are not easily represented on spatial maps including socio-economic, political, defence and security factors, seascape aesthetic and human health-related concerns, factors that were not examined in this thesis. All aspects should be integrated appropriately into the broader marine management approach and stakeholder involvement and participation in every stage of area-based management planning is crucial for optimisation and increased compliance [541].

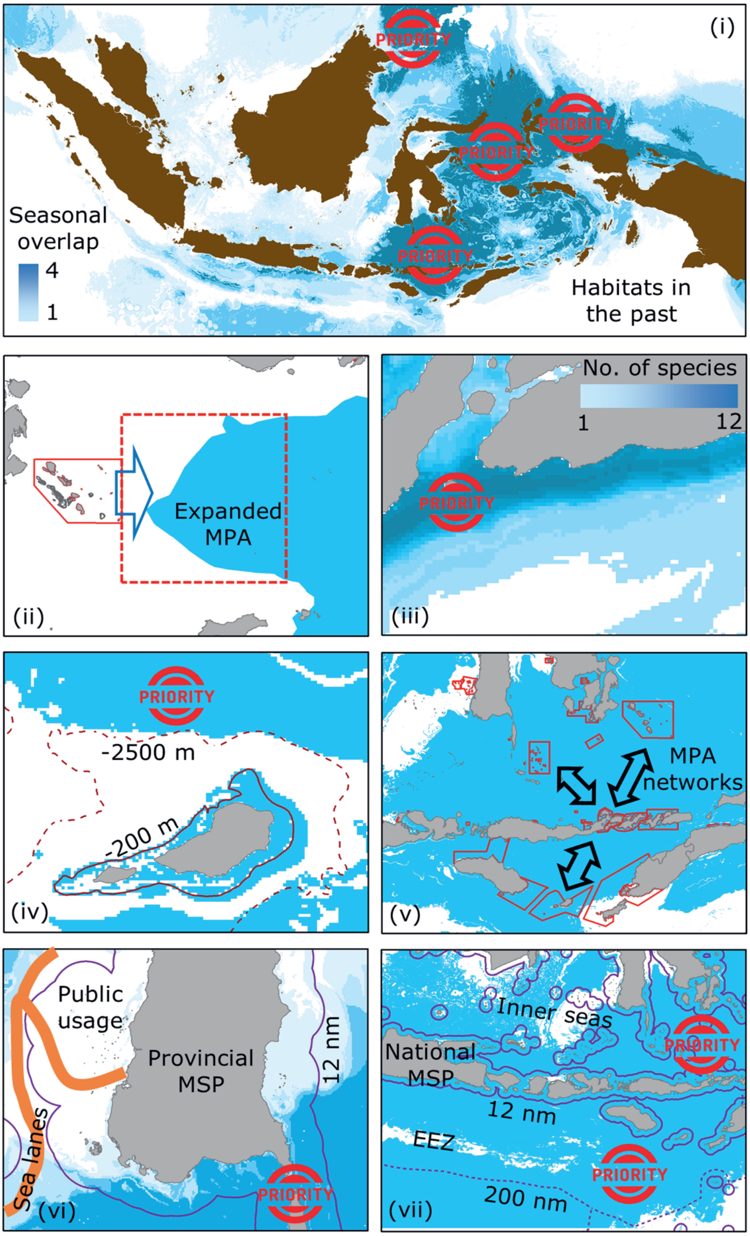

Fig. 7.2. Proposed strategies to incorporate cetacean key habitats into area-based management tools in the process of habitat-use-based spatial planning. Areas prioritised for cetacean conservation, MPA to be extended, and suggested MPA networks are indicated. Further explanation can be found in the text of paragraph 7.3.2 referring to the numbers i-vii.

Although the occurrence and impact of marine mammal bycatch in Indonesia is understudied and debated in Indonesia, managing this bycatch is expected to improve current conservation management success [54,239] (Chapter 2). Several regulations for bycatch reduction have been stipulated (Chapter 2), although the effectiveness of these regulations is uncertain due to lack of robust bycatch data [54]. Interestingly, a market-based approach with 'sustainability' framing to reduce bycatch was recently issued by the US government as an implementation of its 'marine mammal protection act' [542]. According to this new rule, fisheries products that are exported to the US will be rejected in 2021, if the exporting countries still practice unfriendly fishing techniques resulting in large marine mammal bycatch. Similar market-oriented export restrictions have been used effectively in the Pacific [543] usually together with 'free cetacean bycatch' fisheries certifications. As Indonesia is one of the largest exporters of fish products worldwide [542], it strives to abide closely to guidelines for reducing marine mammal bycatch in fear of losing access to the important US market. So, even without exactly knowing the bycatch numbers, this measure will reduce cetacean bycatch in Indonesia too.

7.4. Future perspectives and recommendations for further research

In this thesis, an interdisciplinary approach was used to bring together various disciplines such as policy and governance, population ecology (species traits and distribution, relative abundance estimates), anthropogenic impact and area-based management (MPAs, MSP, marine park zoning system). It is demonstrated that the application of habitat-use-based spatial planning can support cetacean conservation in Indonesia by employing multiple methods and available datasets. It is discussed that to enable cetacean conservation management to evolve further, the following research is needed and work remains to be done:

<u>First</u>, to make current protection governance for marine mammals in Indonesia more effective, the regulation coverage, responsibilities and the degree of enforcement should be assessed. The governance analysis addressed a number of gaps and further research should be devoted to closing these. The conflict between the Ministry of Environment and Forestry and Ministry of Marine Affairs and Fisheries needs to be resolved immediately. Cooperation for achieving the obligations for transboundary management set out under the regional collaborations has historically been slow and ineffective. Investigation on how cross-institutional coordination and multinational collaborations can strengthen effective national legislation may stimulate interest in this.

<u>Second</u>, evolving datasets are needed i.e., time series data with larger spatial coverage and for more species. With the limited number of sighting data, it was not possible to model seasonality for most species (Chapter 4), instead only the spatial dimension of species distribution could be modelled. The consistency of data across

time and space is imperative for future research to support analysis of changes and trends over time and space. As highlighted in Chapters 4 and 5, a higher resolution of shipping footprint data including small vessels in coastal areas are required. Other anthropogenic threat data and their magnitude should be considered in future research, including: fisheries, tourism, pollution, coastal-offshore development, energy production, resources extraction, climate change etc. Unavailability of such data constrained the incorporation of these threats in the current study. Another area for research to expand within the context of data is including information covering the full animal life cycle. A problem of data availability emerged, because of organisational barriers that prevented public data sharing and use. These difficulties in data availability, access and sharing may be tackled through fostering initiatives for open access, sharing and harmonisation of data among the public administrations involved (with strict data filtering and ground truth). Based on the larger available datasets, also projecting habitat modelling to future times with climate change scenarios could be a new direction for further research.

Third, joint multi-national cetacean monitoring scheme, like the SCANS programmes (https://synergy.st-andrews.ac.uk/scans3/) in the European countries, should be initiated in order to collect data from wider geographic areas covering full life cycles of the larger whale species. This scheme will also strengthen the cooperation among neighbouring countries sharing the same marine system. The monitoring scheme can be proposed under the ASEAN's biodiversity initiative that has a specific Working Group on Nature Conservation and Biodiversity [544]. From the marine mammal perspective, an ASEAN-wide agreement will complement the CTI, since only three ASEAN nations are members of CTI.

Fourth, new research opportunities can also be found in further exploring which additional research methods can complement the findings of the present study. Photography, video recording and fin ID can improve species identification. Measuring survey effort per km or hour using GPS tracks rather than sightings per day (as used in Chapter 6), as well as standardising survey platforms and increasing spatial coverage can refine relative abundance estimates of cetacean species [126]. Passive acoustic methods [403,479] can be used in recording cetacean occurrence in rough-weather months or hard-to-access locations. The recent advances in molecular techniques can also aid species identification, and assess species presence/absence and population structure [545,546]. The telemetry methods will become more applicable with tag miniaturisation development [26]. Studies used natural tags (e.g., trace elements and stable isotopes) showed great promise for determining animal movements [547,548]. Additional information on cetacean occurrences may be obtained through the use of novel data types, called 'citizen sciences' [511,512] e.g., from social media.

Fifth, market-based approaches such as the marine mammal protection act in the US to reduce marine mammal bycatch in fisheries need to be further studied in the context of the politics between resource owning and resource exploiting countries and resource importing countries.

Sixth, habitat-use-based spatial planning is not developed in isolation and not all ocean spaces could be blocked for cetacean conservation only. Hence, reconciling spatio-temporal scale is required by optimising synchronisation with human space users, such as by time-area closure. As the ocean system and anthropogenic uses are inherently dynamic, area-based management approaches should enable regular updating to make it adaptable to future developments.

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Summary

Summary

Assessing and improving the effectiveness of conservation management of migratory species such as cetaceans, requires information on governance practise in relation to the animals' ecology. The governance should cover all essential aspects of the cetacean conservation management and if not, the question is what aspects have priority to improve. Important ecological data such as cetacean key areas (including spatio-temporal distribution and occurrence patterns, habitat use and preference, home range, and migratory corridors) and abundance estimates are needed to identify conservation hotspots for area-based management. Incorporating cetacean key habitats into area-based management tools such as marine spatial planning (MSP) and marine protected areas (MPAs) ('habitat-use-based spatial planning') is imperative to optimise cetacean conservation efforts. Obtaining such information in Indonesia, however, is challenging. It is not only because cetaceans are elusive species, but also logistical and budgetary constraints often impede dedicated surveys. Considering the sparse cetacean information available, smart use of datasets obtained via alternative observation methods could prove useful in determining conservation hotspots and priorities. This PhD thesis aimed to develop an approach to provide information to improve cetacean conservation management in Indonesia through suggestions for strengthening the governance and introduction of habitat-use-based spatial planning using complementary methods and underused data.

The first part of the thesis reviews Indonesian marine mammal conservation governance, legal framework, institutional arrangement, and related policies. This showed that Indonesian marine mammal management policy follows most principles mentioned in international conventions. In the development of the legal framework regarding marine mammal governance, three different phases can be distinguished: 1970s following a species-centred approach, 1990s focussing on site-based approaches, and currently applying a wider marine management approach. There are currently 7 policies in place for marine mammal management in Indonesia, either focussing on species-specific, sites or other characteristic values. Despite the set of regulations for marine mammal protection Indonesia currently provides, the study argued that this legal framework and institutional arrangements could be further strengthened. Some aspects of marine mammal conservations governance are missing, these include a legal basis regulating traditional whale hunting, a code of conduct for marine mammal tourism, standards for ex-situ marine mammal conservation, a marine mammal stranding network, and regulation of underwater noise pollution. Suggestions were provided to strengthen the current legal framework such as adapting institutional arrangements to remove functional overlaps and to solve unclear mandates and responsibility dualism. This study also suggests to add more and adapt MPAs for marine mammals and to reinforce international collaborations, including become a full member of the International Whaling Commission and ratify the Convention on the Conservation of Migratory Species of Wild Animals to further bolster Indonesian marine mammal conservation management (Chapter 2).

The second part of the thesis (Chapter 3-6) focuses on identifying cetacean key areas as conservation hotspots for area-based management input and to inform habitat-use-

based spatial planning. As current records of whale occurrence covering the whole of Indonesian waters are limited, this study employed historical whaling data (1761-1920) to model former seasonal distribution and habitat preferences of sperm whale. Two habitat modelling methods were used, Maximum Entropy (Maxent) and Generalised Additive Modelling (GAM). The models combined historical whaling data with submerged topographic variables and revealed that sperm whale occurrences were related to the distance to the coast, deep waters (-1,000 and -5,000 m isobaths) and submarine key features (trough and trench). Both Maxent and GAM showed similar predicted habitat suitability, with Maxent performing better than GAM with higher precision. The results indicate that in four areas in the eastern part of Indonesia, no seasonal differences occurred in sperm whale distribution, while noticeable seasonal differences were found in other areas. The predicted historical distributions were significantly larger than the current ones, another example of a shifting baseline caused by (historical) exploitation. The study demonstrates how incorporating historical data (such as from the 18th-20th centuries whaling) into habitat models can benefit ecological investigation to inform conservation efforts. Information on critical habitats and seasonal variability from this study can be used to direct future monitoring program, provides a baseline to assess present distribution of the species, and as an input for MPA and MSP establishment (Chapter 3).

To support national cetacean conservation and management planning with up-to-date information on cetacean spatial distribution and habitat preference, Maxent was used to model the distribution of 15 selected cetacean species in 7 ecoregions/seascapes in Indonesia using pooled recent multi-source cetacean presence data (2000-2018) and topographic-oceanographic variables. The individual species habitat maps revealed a great heterogeneity in distribution among species and within species among different locations. This heterogeneity reflects an interrelated influence of topographic variables and oceanographic processes on the distribution of cetaceans. Bathymetry, distance to- coast and -200 m isobaths, chlorophyll-a concentration (Chl-a) and sea surface temperature (SST) were important variables influencing distribution of most species in many regions. Areas rich in species were mainly related to coastal areas or insular-reef complexity, representing high productivity and upwelling-modified waters. Species traits such as deep diver or estuarine related species, also reflected in model outputs. The combined species habitat maps were overlaid with provincial MSP jurisdictions, MPAs, oil-gas contract areas, and marine traffic density to assess spatial overlaps. Although some suitable habitats are currently covered by MPAs, other important areas are not and instead overlap with oil-gas contract areas and marine traffic, indicating potentially high risks for cetaceans. The results provide priority areas and can be used as a basis for anthropogenic threat mitigation. It is advised to consider important currently unprotected cetacean habitats in future MPA and MSP development (Chapter 4).

Marine migratory species, including large cetaceans, tend to be overlooked in Indonesian MSP due to the limited knowledge of their habitats and migration pathways. This results in a disconnect between animal migration ecology and spatial planning decision making. Telemetry-based home range analysis and habitat modelling were performed to picture yet hardly considered parts of the pygmy blue whale's (PBW) life cycle including migration. Based on available telemetry data (2009 and 2011), home ranges, core-use areas and migratory corridors were determined using Brownian Bridge Movement Modelling (BBMM). Further, habitat suitability was then predicted by modelling the telemetry data against known environmental predictors using Maxent. The study showed a consistent movement of PBW from Western Australia to the Banda and Molucca Seas in Indonesia, demonstrated a high level of connectivity between the two regions. Route fidelity, dispersal, and high residency of PBW in certain areas were recognised. Home ranges differed in size and shape among individual PBWs. Shifts in SST and the presence of localised productivity along migration pathways are presumed to drive and support the PBW migration. The resulting information was then applied to assess overlap with marine reserves, designated migration lanes, and areas with high marine traffic density. A discrepancy was observed between the legally designated migration lanes for large whales in Indonesia and migration routes unveiled by this study. Clearly, large areas of migration corridors, core-use areas, and suitable habitats are currently not protected in mainly international waters and the Banda-Molucca Seas, an input for further conservation actions. The results support the needed adjustment of designated migration lanes and current MPA boundaries. Multi-national collaborations are encouraged for protecting cetacean key areas in the high seas (Chapter 5).

Effective management and proper zoning design of MPAs with cetaceans necessitate understanding of animal's spatio-temporal occurrence patterns and other ecological knowledge. Obtaining such information, however, is challenging especially for under-studied tropical marine parks. As a cost-effective alternative for the lacking systematic survey data in Wakatobi National Park (WNP) Indonesia, data from platforms of opportunity and incidental sighting data (2004-2012) were used to assess cetacean diversity, spatio-temporal occurrence patterns, habitat preferences, and to estimate sighting frequency. Of the 11 cetacean species identified, spinner and bottlenose dolphins were sighted most often, followed by melon-headed and sperm whales. Spatial occurrence patterns of these four most sighted species differed in relation to reef habitat types, park zoning system, and depth preference. Also the temporal occurrence patterns of these species differed seasonally, and the sighting frequency of cetaceans varied inter-annually. All cetaceans were reported mostly during inter-monsoonal seasons, possibly related to increased prey availability due to seasonal upwelling and increased survey activity. Also, additional information on cetacean behaviours, mother-calf pairs, and fishing interaction were revealed. Interestingly, most cetacean sightings occurred in the WNP use-zones and nothing in the park core zone, suggesting a mismatch between park zoning design and the cetacean ecological needs. This study demonstrates the use of platforms of opportunity as a cost-effective tool to provide valuable data on cetacean occurrence in areas with limited survey resources. While data collection can be further improved, the results presented here already help identify potentially important areas as well as highlight where to direct designated research efforts. It is suggested to protect currently unprotected important cetacean habitats, and strictly regulate human activities in the current use zones in future WNP rezoning processes (Chapter 6).

Several strategies for incorporating migratory species' key habitats into the Indonesian MPAs and MSP are proposed: (i) consider sperm whale habitats from the past (Chapter 3) focusing on core habitats that persist over seasons; (ii) expand existing MPAs that are located near the newly identified cetacean key habitats (Chapter 3-6); (iii) prioritise the habitats that are used by more than one species (Chapter 4); (iv) develop new MPAs that are located in the deep-water habitats to represent previously these neglected key habitats (Chapter 3-6); (v) take cetacean key habitats (Chapter 3-6) into account to guide MPA networks establishment; (vi) incorporate cetacean key habitats within MSP's conservation zones during the review process; and (vii) accommodate cetacean key habitats (Chapter 3-6) in the National MSP (EEZ and inner seas). Additional mitigation measures such as reducing bycatch, regulating fishing gears and adjusting shipping lanes are also needed for managing cetacean key habitats that overlap with human activities.

This thesis demonstrates the use of multi-method and multi-dataset approaches to identify key governance aspects and acquire ecological data of cetaceans in under-studied tropical equatorial regions of Indonesia that also are applicable elsewhere in the world. Applying different methods and available datasets can complement each other and thereby strengthen the outcome of the research, especially for under-studied areas and for poorly known cetacean species. The study also added new knowledge about the cetacean spatial distribution, occurrence patterns, habitat use and preference, home range, migratory corridors, and about the status of under-studied cetacean populations and their relative abundance estimates. While efforts to accumulate knowledge on the lesser known aspects of cetacean species need to be continued, the information that is already available here can feed current decision-making related to conservation planning and management of cetacean species. The findings from this thesis further stress the importance of refining key governance aspects and including previously ignored aspects of cetacean ecology and key areas into habitat-use-based spatial planning to optimise these migratory species conservation.

Appendices

Acknowledgements

About the Author

List of Publications

Training and Education

Acknowledgements

The accomplishment of this PhD is made possible through the help of many individuals throughout my PhD journey that enabled me to finish this thesis within 4 years. I would like to take the opportunity to express my gratitude to all the people who helped me reach this point.

First of all, I would like to express my sincere gratitude to my promotor, Prof. Tinka Murk, for giving me the opportunity to do my PhD in Marine Animal Ecology (MAE) Group. After contacting 6 other professors in the Netherlands without getting a response, your reply to my email was the beginning of my new adventure. It was in the middle of summer in 2016, when you invited me for the first time to meet you in your office. You scheduled an hour meeting for us, but then it lasted for 3 hours, with satisfying results: when I left your office room, I brought a letter of acceptance and good PhD proposal that was finally granted by LPDP scholarship. I also thank you for your regular supervision, continuous support and motivation. You are very inspiring in finding knowledge gaps in my research topic and without your unique perspectives, this thesis would have been completely different. A PhD project is not only about answering scientific questions, but also training persons for being good at finding and solving problems. Next, I would like to give a heart-felt thank to my co-promotor, Dr Putu Liza Kusuma Mustika (Icha), for the supervision and encouragements. Throughout the thesis you have been a constant source of advice and guidance. I really enjoyed our time discussing papers and other matters with you. Your comments on our manuscripts have always been spot on and important in navigating the peer review processes. I would like to thank Prof. A. Syafei Sidik (Universitas Mulawarman) and Prof. Agus Hartoko (Universitas Diponegoro) for giving me reference letters for applying for the LPDP scholarship. Your references opened the door that led to my PhD.

Many thanks to the co-authors of my publications. Iqbal, we have had many discussions about our data and habitat modelling. It would not have been possible to collect such a complete dataset without your help. Yoga, thanks for providing me with all the regulation documents and GIS data needed for my analyses. Virginia and Mike, without the telemetry data, the Chapter 5 would never have been written. Meike, whenever I was struggling, you repeatedly took time to help me reorganising my thoughts. I really appreciated your feedback and analytical views, and it resulted in a fantastic piece of work in Chapter 6. Thanks to Charlotte and Ron for the wonderful collaboration we had for Chapter 5, to Danielle for Chapter 4, and to Purwanto for Chapter 6.

My next sincere acknowledgments go to the members of the reading committee, Prof. Turnhout, Em. Prof. Reijnders, Dr Groen, and Dr Newlands for willingness to read and evaluate my PhD thesis. I would like to express my gratitude to The Nature Conservancy Indonesia (now Yayasan Konservasi Alam Nusantara), WWF Indonesia, Balai Taman Nasional Wakatobi, Pemda Wakatobi, and all monitoring staff who have endeavoured to collect and archive valuable dataset. Thanks to Neftalí Sillero and Geert Aarts who helped me a lot in habitat modelling. Also, to Yusuf Fajariyanto, Doddy Yuwono and Rokhman Khabibi for your generosity in sharing data, to Pak Dadan for your input to my first paper outline, and to Mas Habib for your useful comments to my General Discussion.

The MAE community has always been an open minded and stimulating pleasant workplace. Thanks to the MAE staff members: Dolfi, Edwin, Lisa, Martine, Maya, Pauline, Reindert, Rene, Ronald, Rosa, Tim, Saskia, and Susan. I always felt welcome here and I have enjoyed my stay at this group. I met lots of excellent people who helped me developing. I would like to extend my gratitude to my wife's promotor, Prof. Ivonne Rietjens, to give my wife a year of external postdoctoral position and to offer me a PhD position at my first year in Wageningen, although eventually I decided to do my PhD in the MAE Group. I would like to thank all my PhD colleagues: Alwin, Annemiek, Antoine, Celia, Christiaan, Diede, Erik, Ewout, Gibbs, Inger (former), Joshua, Karlijn, Lara, Ludi, Mischa, Niels, and Park. Thank you for the fantastic scientific and non-scientific atmosphere, for having a listening ear for all my concerns (I don't like Dutch 'rainy and cold' weather!), and for the conversations we shared about ups and downs in (PhD) life. Diede and Christiaan, there was not a single time that you were not helpful or that you were 'too busy' to answer my questions (about R scripts, statistical analysis, translating Dutch letters [also to Lara] etc.). I am so grateful for your kindness. Thanks Christiaan for giving my kids monthly Donald Duck magazines. I would like to extend my gratitude to my paranymphs, Ludi and Diede, for helping and preparing everything for my defence. I would like also to thank my former MSc students Yitno, Debby, Afrita, Floor, and Charlotte for their contributions.

I am also thankful for the support from my Indonesian friends in Wageningen that makes me feel that the Netherlands is not a foreign country to me anymore. Widhya N. Satrioajie and Arif D. Santoso, you are the first Indonesians who I met here (also Pak Eko and Pak Ery) and always gave me helping hands. The parents of my children's friends in the Openbare Basisschool (OBS) de Tarthorst: Mbak Aulia-Pak Dikky, Mas Zukri, Mbak Najmi, Mas Anto-Mbak Nila, Mbak Fifi, Mbak Andra, Pak Gede, Mas Anto-Mbak Uun, Mas Hardi-Mbak Eva, and Nove for keep watching my sons after school, during the weekend, or when both of us were unable to accompany them due to our conflicting schedules. I also would like to thank the Indonesian PhD-Postdoc community for sharing experiences about PhD life in WUR: Pak Gede-Mbak Nimas, Pak Dikky, Mas Fariz, Mas Emil, Pak Fajar, Teh Novi-Kang Indra, Pak Iman, Koh Sony, Mas Taufik, Mas Ayusta, Mas Alim, Mas Gumi-Mbak Gendis, Mas Hachi, Mbak Windi, Mbak Aviv, Mbak Atik, Vina-Farid, Mbak Titis (Apdini & Wardhani), Mbak Nadya, Mas Robbith. Thanks Mas Satria and Mas Anto for helping and sharing experience about cars, and to many others who I could not mention one by one. My extended thanks also to my sons' teachers at the OBS de Tarthorst and Sekolah Indonesia Den Haag. Thanks to Yasin-Taklim Wageningen and PCINU Belanda especially Mas Faris, Mas Firin, Mas Latif Fauzi, Mas Shohib, Mas Fachrizal, Mas Yance, Mas Adrian, Mas Syahril, Mas Advan and Mbak Yus, for the gathering, helping each other, and more life than merely doing PhD. Thanks to Yai Hasyim and Ustadz Fatah for being our spiritual mentors, and my Hajj friends: Bu Yeni-Pak Wim, Bu Armis, Bu Berni, Bu Ita-Pak Akmal, Bu Efi-Mr. Daniel, Bu Teti, Mas Fikri, Mas Harry, Mas Andie and Bu Iik for the togetherness. Thanks the previous Indonesian MSc students at WUR: Lisa, Isna, Atina, Rausan-Icha, Ikrom, Iqbal, Yitno-Astin for helping us to take care our sons during Hajj; Icha and Arif thanks for being caregiver of my sons after their school day; Tombayu for answering my questions on GIS analysis; Imron, Wira, and Zakky for regularly cutting my hair. Thanks to the current Indonesian MSc students, Nove, Kukuh, Ikbar, and Yaqin, for the friendship. I would like to thank my former lecturers and colleagues from Universitas Diponegoro who visiting us when they came to WUR/NL: Prof. Ocky, Prof. Sri Rejeki, Mbak Resti, Mbak Riri, Mbak Tita, and Mas Purwanto; also UNISSULA delegates: former Rectors Pak Anis Malik and Pak Prabowo, current Rector Pak Bedjo Santoso, Prof. Imam Wahyudi, Bu Henny, Pak Rachmat Mudiyono, and Bu Endang.

Above all, I have to thank my dear wife Suparmi and my beloved children *Kak* Brillant and *Adek* Abil. I am fortunate to have family who always supports and encourages me to accomplish things in life. I am grateful to you for giving love and strengths during my difficult moments. My dear wife, both working on our PhD at mostly overlapping time and raising our sons together was a challenging adventure. I am glad that we experienced this journey together and both our PhDs are finished on time. Together we make it happen!

I also thank my family in Indonesia for giving endless moral support, despite the long distance between us: *Abah* H. Washlih Thohir (alm.), *Mimih* Hj. Masfuah, all my siblings (thanks Nana for preparing documents and everything I needed) and my wife's family, especially *Pake* Tarji (alm.), *Mbah* Ni, and Sulis. Finally, my PhD would not have been possible without the scholarship from the Indonesia Endowment Fund for Education (LPDP) from the Ministry of Finance of the Republic of Indonesia. I am very grateful for the financial support provided.

About the Author

Achmad Sahri was born on 1 July 1982 in Brebes, Central Java, Indonesia. He obtained his BSc degree in 2008 from Marine Science Bachelor Program in Faculty of Fisheries and Marine Science, Universitas Diponegoro, Semarang, Indonesia. His BSc thesis was about the application of Geographical Information Systems (GIS) for mapping of grouper's mariculture site selection in Karimunjawa National Park, Indonesia. In 2013, he obtained his MSc degree in the Master Program of Coastal Resource Management at the same university, financially supported by *Beasiswa Unggulan* from the Indonesian Ministry of National Education (Depdiknas RI). He wrote his MSc thesis on deterministic habitat suitability modelling for the management of Asian Moon scallops in the Brebes waters.

In the period of 2010-2014, he was employed at The Nature Conservancy - Indonesia Marine Program as a Conservation Coordinator. He helped the Authorities of Wakatobi National Park and Derawan Islands Coastal Park in monitoring their conservation targets, one among them was on cetaceans, where the data collected from the monitoring programs were eventually used for his PhD. In 2011, he was involved in a technical team supervised by the Indonesian Man and Biosphere (MAB) National Committee - Indonesian Institute of Sciences (LIPI) for nominating Wakatobi as a World Biosphere Reserve. Wakatobi was indeed declared as the 8th Biosphere Reserve in Indonesia by the MAB-UNESCO on 11 July 2012 in Paris, France. In March 2013, he attended the Conservation Coaches Training workshop in Cairns, Queensland, Australia held by The Nature Conservancy Australia and the Conservation Coaches Network. He was involved in MPA management, working as a technical team member for the establishment of Marine and Small Islands Conservation Areas in Berau, East Kalimantan from 2013 to 2014. This work was successfully finalised with the stipulation of Derawan Islands Coastal Park by a Regent Decree in 2014 (and finally with a Ministerial Decree in 2016).

In 2017, he was awarded a scholarship from the Indonesia Endowment Fund for Education (LPDP) from the Indonesian Ministry of Finance. He started his PhD in the Marine Animal Ecology (MAE) Group, Wageningen University and Research at the same year. His PhD research was inspired by his previous work and intended to advocate a neglected aspect in Indonesian marine conservation and spatial planning i.e., to incorporate critical habitats and migration corridors of marine migratory species in area-based management tools such as marine protected areas (MPAs) and marine spatial planning (MSP). Different from his MSc thesis, he applied stochastic instead of deterministic habitat modelling approaches for his PhD research. His interests and work on topic of MPAs, marine wildlife management and MSP grew during his PhD. In 2018, he attended the Important Marine Mammal Area (IMMA) workshop in Kota Kinabalu, Sabah, Malaysia and proposed two areas (Wakatobi for cetaceans and Toli-toli for dugongs) as IMMA candidates. These two areas were eventually declared as IMMAs in 2019 by the Marine Mammal Protected Areas Task Force of the International Union for Conservation of Nature (IUCN).

List of Publications

Peer-reviewed publications

1. **A. Sahri**, P.L.K. Mustika, H.Y. Dewanto, A.J. Murk. (2020). A critical review of marine mammal governance and protection in Indonesia. Marine Policy, 117C: 103893. https://doi.org/10.1016/j.marpol.2020.103893.
2. **A. Sahri**, M.I.H. Putra, P.L.K. Mustika, A.J. Murk. (2020). A treasure from the past: Former sperm whale distribution in Indonesian waters unveiled using distribution models and historical whaling data. Journal of Biogeography, 7(10): 2102-2116. https://doi.org/10.1111/jbi.13931.
3. **A. Sahri**, P.L.K. Mustika, P. Purwanto, A.J. Murk, M. Scheidat. (2020). Using cost-effective surveys from platforms of opportunity to assess cetacean occurrence patterns for marine park management in the heart of the Coral Triangle. Frontiers in Marine Science, 7: 569936. https://doi.org/10.3389/fmars.2020.569936.
4. **A. Sahri**, M.I.H. Putra, P.L.K. Mustika, D. Kreb, A.J. Murk. (2021). Cetacean habitat modelling to inform conservation management, marine spatial planning, and as a basis for anthropogenic threat mitigation in Indonesia. Ocean and Coastal Management, 205: 105555. https://doi.org/10.1016/j.ocecoaman.2021.105555.
5. **A. Sahri**, C. Jak, M.I.H. Putra, A.J. Murk, V. Andrews-Goff, M.C. Double, R.J. van Lammeren. Telemetry-based home range and habitat modelling reveals that the majority of areas important for pygmy blue whales are currently unprotected. *Under review*. Biological Conservation (submitted in October 2020).

Abstracts in conferences and workshops

1. **A. Sahri**, M.I.H. Putra, P.L.K. Mustika, A.J. Murk. Cetacean habitat suitability in Indonesia: An effort to provide their more detailed distributions, **In**: Important Marine Mammal Areas (IMMAs) Workshop, for the North East Indian Ocean and South East Asian Seas held by the IUCN Marine Mammal Protected Areas Task Force, 12-16 March 2018, Kota Kinabalu, Sabah, Malaysia.
2. **A. Sahri**, M.I.H. Putra, P.L.K. Mustika, A.J. Murk. Reveal former sperm whale distribution in Indonesian waters based on historical whaling data using habitat models, **In**: Wageningen Indonesia Scientific Exposure (WISE 2019): "United in Science Diversity: Bringing Indonesian Wageningen Together", 12 March 2019, Orion Building, WUR Campus, Wageningen, The Netherlands.
3. **A. Sahri**, A.J. Murk. Habitat use by cetaceans in the heart of the Coral Triangle, **In**: WIAS Science Day 2019: "Trade-offs in science - keeping the balance", 18 March 2019, De Werelt Conference Centre, Lunteren, The Netherlands.
4. **A. Sahri**, A.J. Murk. Cetacean movement for marine conservation and spatial planning in the heart of the Coral Triangle, **In**: Postgraduate course - Animal

Movement Analysis, 30 June - 5 July 2019, University of Amsterdam, Amsterdam, The Netherlands.

5. **A. Sahri**, M.I.H. Putra, P.L.K. Mustika, A.J. Murk. Revealing former sperm whale distribution in Indonesian waters based on historical whaling data using habitat models, **In**: World Marine Mammal Conference (WMMC 2019), 9-12 December 2019, Centre de Convencions Internacional de Barcelona, Barcelona, Catalonia, Spain.
6. **A. Sahri**, M.I.H. Putra, P.L.K. Mustika, A.J. Murk. A treasure from the past: Modelling former sperm whale distribution with historical whaling data, **In**: WIAS Annual Conference 2020: "Frontiers in Animal Sciences! Lessons from the past, Challenges of the present, Aspirations for the future", 13-14 February 2020, De Werelt Conference Centre, Lunteren, The Netherlands.

Supervised MSc Thesis

1. Cetacean management in Indonesia: Current update on cetacean occurrences and the governance of cetacean protection. MSc Thesis - Aquaculture and Marine Resources Management (MAM) & Marine Animal Ecology (MAE) Group WUR (2018).
2. Uncovering the movement patterns of cetaceans in Wakatobi-Indonesia from long-term opportunistic data. MSc Thesis - Aquaculture and Marine Resources Management (MAM) & Marine Animal Ecology (MAE) Group WUR (2019).
3. Habitat modelling of whales in Indonesia. MSc Thesis - Aquaculture and Marine Resources Management (MAM) & Marine Animal Ecology (MAE) Group WUR (2019).
4. Predicting cetacean habitats beyond surveyed regions in Indonesian waters. MSc Thesis - Geographical Information Management and Applications (GIMA) UU-TU Delft-WUR-UT & Marine Animal Ecology (MAE) Group WUR (2020).
5. An evaluation of the Indonesian & Australian Marine Protected Areas (MPAs) regarding the habitat and migration corridors of the Pygmy blue whale (*Balaenoptera musculus brevicauda*): Comparing different methods to delineate the whale distribution. MSc Thesis - Geo-Information Science and Remote Sensing WUR & Marine Animal Ecology (MAE) Group WUR (2020).

Training and Education

With the training and education activities listed below, **Achmad Sahri** has complied with the requirements set by the Graduate School of the Wageningen Institute of Animal Sciences (WIAS) which comprises of a total of 37 ECTS (1 ECTS equals a study load of 28 hours).

Training and Education	**Year**	**ECTS***
A. The Basic Package:		***3***
- WIAS Introduction Day, *WUR*	2018	
- Research Integrity & Ethics, *WUR*	2018	
- Introduction to Personal Effectiveness, *WUR*	2019	
B. Disciplinary Competences:		***12***
- Writing WIAS Research Proposal	2017	
- Statistics for the Life Sciences, *WUR*	2018	
- Ecological Niche Modelling, *Barcelona*-Spain	2018	
- Animal Movement Analysis, *UvA Amsterdam*-NL	2019	
C. Professional Competences:		***9***
- Techniques for Scientific Writing & Presenting, *WUR*	2018	
- Supervising BSc and MSc Thesis Students, *WUR*	2018	
- Presenting with Impact, *WUR*	2018	
- Organising Committee - Wageningen Indonesia Scientific Exposure (WISE)	2019	
- Reviewing a Scientific Paper, *WUR*	2019	
- Efficient Writing Strategies, *WUR*	2019	
- The Final Touch: Writing the General Introduction & Discussion, *WUR*	2019	
- Scientific Writing, *WUR*	2021	
D. Societal Relevance:		***3***
- Communication with the Media and the General Public, *WUR*	2018	
- Societal Impact of Your Research, *WUR*	2019	
E. Presentation Skills:		***4***
- Important Marine Mammal Areas Workshop, *Kota Kinabalu*-Malaysia (oral)	2018	
- Wageningen Indonesia Scientific Exposure, *Wageningen*-NL (pitch & poster)	2019	
- WIAS Science Day, *Lunteren*-NL (pitch & poster)	2019	
- World Marine Mammal Conference, *Barcelona*-Spain (poster)	2019	
- WIAS Annual Conference, *Lunteren*-NL (pitch & poster)	2020	
F. Teaching Competences:		***6***
- Supervising MSc Thesis (5 Students)	2017-2019	
- Tutoring MSc 'Marine Animal Ecology' Course Practicals, *WUR*	2018-2019	
Total (minimum of 30 ECTS)		**37**

*ECTS: European Credit Transfer and Accumulation System

The research described in this thesis was financially supported by the Indonesia Endowment Fund for Education (LPDP) from the Ministry of Finance of the Republic of Indonesia through a doctoral scholarship for Achmad Sahri (award number: PRJ-482/LPDP.3/2017).

Colophon
Front cover: A cetacean monitoring activity in Wakatobi National Park (below, credit photo: Purwanto), and the visualization of cetacean hotspots on Indonesian map (above, source: the World Ocean Base map from Esri, Garmin, GEBCO, NOAA NGDC, and other contributors).
Back cover: A representation of Pygmy blue whale's migration corridor on submerged topography (source: the World Ocean Base map from Esri, Garmin, GEBCO, NOAA NGDC, and other contributors).
Cover & layout design: Sigit Pamungkas and Achmad Sahri
Printed by: Proefschriftmaken

Financial support from the LPDP and Marine Animal Ecology (MAE) Group, Wageningen University for printing the thesis is gratefully acknowledged.