Survival probabilities of thornback and spotted rays discarded by beam trawl and flyshoot fisheries

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Summary

Elasmobranchs (i.e. sharks, skates and rays) play an important role as predators in marine ecosystems. In the last century the abundance of several ray populations in the North Sea declined. Their specific life-history traits, i.e. being long-lived, showing slow growth, late sexual maturity and producing a small number of young per year, make them vulnerable to fishing, pollution and changes in essential habitats, especially spawning and nursery areas. Since 2010 a recovery in the abundances of some species is observed.

Landings of skates and rays in European waters are generally managed by a group-TAC, meaning several species are managed under a single Total Allowable Catch (TAC). In the North Sea this group-TAC applies to thornback (*Raja clavata*), blonde (*Raja brachyura*), spotted (*Raja montagui*) and cuckoo ray (*Leucoraja naevus*). Landings of starry ray (*Amblyraja radiata*) and common skate (*Dipturus sp.*) are prohibited. In Dutch fisheries, skates and rays are mainly caught as by-catch in the mixed demersal fishery for flatfish, with landings dominated by thornback ray. For these species the rays below minimum landing size and catches that exceed the vessel's weekly trip limits are discarded. Since 2019 this practise of discarding has been restricted for all quota regulated species, including rays, by the implementation of a landing obligation under the Common Fisheries Policy (European Union, 2013). The objective of the landing obligation is to create an incentive for fishers to avoid unwanted bycatches and thereby reduce discards rates. The European commission granted a temporary 'high survival' exemption for rays and indicated that for this exemption to be renewed or extended beyond 2023, knowledge gaps regarding discards survival probabilities of rays, as laid out in the "Roadmap skates and rays", need to be filled. The current study therefore aims to contribute to this roadmap by filling main gaps in our knowledge on the survival probability of rays when discarded by the most important Dutch demersal fisheries.

Beam trawl and flyshoot fisheries are quantitatively the main contributors to ray catches by Dutch demersal fisheries with thornback and spotted ray as main species. These two métiers and species were therefore selected for the discards survival experiments. We conducted five trips with a beam trawler during which 184 thornback and 140 spotted rays were sampled and four trips with a flyshooter during which 134 thornback and 28 spotted rays were sampled. Survival probabilities were measured by captive observation of these rays up to 25 days post-capture. Control rays were used to separate potential effects of the experimental procedures on mortality from fisheries-induced mortality. All fishery operations were conducted in the southern North Sea (ICES division 27.4.c) and in the English Channel (ICES division 27.7.d) according to the regular commercial practices of the fishing vessels. Trips were allocated to different quarters over the year to account for the effect of variable environmental and fishing conditions on discards survival. Operational and environmental conditions during sea trips were recorded.

In this study we established the following discards survival probabilities (95% CI):

- 45.5% (37.9-54.5) for spotted ray discarded by tickler chain beam trawl fisheries with 80 mm cod-end meshes;
- 49.6% (42.9-57.4) for thornback ray discarded by tickler chain beam trawl fisheries with 80 mm cod-end meshes;
- 77.6% (63.3-95.2) for spotted ray discarded by flyshoot fisheries with 80 mm cod-end meshes;
- 81.0% (74.4-88.2) for thornback ray discarded by flyshoot fisheries with 80 mm cod-end meshes.

The experimental procedures did not cause any mortality since all control rays survived the experiments. All mortality among sampled rays can thus be considered to be fisheries induced. Survival probability was higher for rays discarded by flyshoot fisheries compared to beam trawl fisheries. Survival probability of discarded rays decreased with increasing seawater temperature and some evidence for decreasing survival with increasing catch processing time was found. Species and body length did not affect survival probability.

Survival probability was highest for rays that were landed on deck in good condition. To further increase survival probability it is recommended to keep catch processing time as short as possible and to focus on gear modifications that reduce stressors inflicted upon fish during the catch and hauling process to increase the proportion of rays that is landed on deck in good condition. In addition, we recommend to pursue reduction of fishing mortality among rays by reducing the amount of caught rays by improved selectivity of fishing gear and by actively avoiding fishing grounds where rays occur in high densities.

Samenvatting

Elasmobranchen (d.w.z. haaien en roggen) spelen een belangrijke rol als predatoren in mariene ecosystemen. In de vorige eeuw is de omvang van verschillende roggenpopulaties in de Noordzee afgenomen. De specifieke levenswijze, namelijk een lange levensduur, langzame groei, late geslachtsrijpheid en een klein aantal jongen per jaar, maakt elasmobranchen kwetsbaar voor visserij, vervuiling en veranderingen in essentiële habitats, met name paai- en opgroeigebieden. Sinds 2010 wordt een herstel van de omvang van sommige soorten waargenomen.

In Europese wateren worden roggen over het algemeen beheerd door een groep-TAC (Total Allowable Catch), d.w.z. dat verschillende soorten onder één totaal toegestane vangst (TAC) worden beheerd. In de Noordzee geldt deze groeps-TAC voor stekelrog (*Raja clavata*), blonde (*Raja brachyura*), gevlekte (*Raja montagui*) en koekoeksrog (*Leucoraja naevus*). Aanlandingen van sterrog (*Amblyraja radiata*) en vleet (*Dipturus sp.*) zijn verboden. Deze soorten worden in Nederland vooral als bijvangst gevangen in de gemengde demersale visserij op platvis, waarbij stekelroggen de aanvoer domineren. Voor deze soorten worden de roggen die kleiner zijn dan de minimale aanvoermaat en de roggenvangsten die de wekelijkse aanvoerlimieten van individuele vissersschepen overschrijden, teruggezet. Sinds 2019 is deze praktijk van terug in zee zetten (discarden) beperkt voor alle soorten waarvoor quota gelden, inclusief roggen, door de invoering van een aanlandingsplicht in het kader van het gemeenschappelijk visserijbeleid (Europese Unie, 2013). Het doel van de aanlandplicht is het stimuleren van vissers om bijvangsten van ondermaatse vissen en vissoorten waarvoor ze geen quota hebben of die geen marktwaarde hebben te vermijden en zo de hoeveelheid discards te verminderen. De Europese commissie verleende een tijdelijke 'hoge overlevings'-vrijstelling voor roggen en gaf aan dat voor vernieuwing van deze vrijstelling na 2023 kennislacunes met betrekking tot de overlevingskansen van teruggegooide roggen, zoals uiteengezet in de "Roadmap roggen", moeten zijn ingevuld. Het huidige onderzoek beoogt daarom de belangrijkste lacunes te overbruggen in onze kennis over de overlevingskans van roggen wanneer deze worden teruggegooid door de belangrijkste Nederlandse demersale visserijen.

De boomkor- en flyshootvisserij leveren kwantitatief de grootste bijdrage aan de roggenvangsten door de Nederlandse demersale visserij met stekelrog en gevlekte rog als belangrijkste soorten. Deze twee métiers en soorten werden daarom geselecteerd voor de discards overlevingsexperimenten. We voerden vijf onderzoeksreizen uit met een boomkorkotter waarbij 184 stekelroggen en 140 gevlekte roggen werden bemonsterd en vier onderzoeksreizen met een flyshooter waarbij 134 stekelroggen en 28 gevlekte roggen werden bemonsterd. Overlevingskansen werden gemeten door observatie van deze roggen in gevangenschap tot 25 dagen na de vangst. Controle roggen werden ingezet om sterfte veroorzaakt door de experimentele procedures te kunnen onderscheiden van sterfte door de visserij. Alle visserijactiviteiten werden uitgevoerd in de zuidelijke Noordzee (ICESdivision 27.4.c) en in het Engelse Kanaal (ICESdivision 27.7.d) volgens de reguliere visserijpraktijk. De reizen werden over het jaar gespreid om rekening te houden met het effect van wisselende visserijomstandigheden op de overleving van de discards. Operationele omstandigheden en omstandigheden op zee tijdens de reizen werden geregistreerd.

In deze studie hebben we de volgende overlevingskansen voor discards vastgesteld (95% betrouwbaarheid intervallen):

- 45,5% (37,9-54,5) voor gevlekte rog teruggegooid door boomkorvisserij met wekkerkettingen en een maaswijdte van 80 mm;
- 49,6% (42,9-57,4) voor stekelrog teruggegooid door boomkorvisserij met wekkerkettingen en een maaswijdte van 80 mm;
- 77,6% (63,3-95,2) voor gevlekte rog teruggegooid door flyshoot-visserij met een maaswijdte van 80 mm;
- 81,0% (74,4-88,2) voor stekelrog teruggegooid door flyshoot visserij met een maaswijdte van 80 mm.

De experimentele procedures hebben geen sterfte veroorzaakt aangezien alle controle roggen de experimenten overleefden. Alle sterfte onder de verzamelde roggen kan daarom worden toegeschreven aan de visserij. De overlevingskans voor roggen die werden teruggegooid in zee was groter voor de flyshootvisserij dan voor de boomkorvisserij. De overlevingskans van teruggegooide roggen nam af met toenemende zeewatertemperatuur en er werd enig bewijs gevonden voor een afnemende overlevingskans naarmate de verwerking van de vangst langer duurde. Soort en lichaamslengte hadden geen invloed op de overlevingskans.

De overlevingskans was het hoogst voor roggen die in goede conditie aan dek kwamen. Om de overlevingskans verder te vergroten, wordt aanbevolen de verwerkingstijd van de vangst zo kort mogelijk te houden en onderzoek te doen naar aanpassingen aan het vistuig die de belasting van de vis tijdens het vangstproces verlagen, zodat het aandeel roggen dat in goede conditie aan dek komt, toeneemt. Daarnaast wordt aanbevolen onderzoek te doen naar het verlagen van visserijsterfte onder roggen door het verlagen van de hoeveelheid bij gevangen roggen door verbeterde selectiviteit van vistuigen en door het actief vermijden van visgronden waar roggen in hoge dichtheden voorkomen.

1 General introduction

Elasmobranchs (i.e. sharks and rays) play an important role as predators in the marine ecosystem (Heithaus et al., 2008). They are characterized by specific biological properties. They are long-lived, slow growing, reach sexual maturity at relatively old age, and produce a small number of offspring per year. These properties make elasmobranchs vulnerable to fishing, pollution and changes in essential habitats, especially spawning and nursery areas (Stevens et al., 2000, Schindler et al., 2002, Heessen, 2010). While there is considerable variation in life history between species and populations of sharks and rays, which may lead to different sensitivity to factors such as fisheries, elasmobranch populations have declined sharply worldwide and a quarter of the species are threatened in their survival (Brander, 1981, Dulvy et al., 2008, Dulvy et al., 2014). The decline of ray populations in the North Sea, especially in the last century, is generally attributed to long-term intensive fishing, as well as large-scale coastal infrastructure and pollution (Walker and Heessen, 1996, Heessen, 2010, Sguotti et al. 2016). However, data from the scientific sampling programs show an increase in populations for a number of species since 2010 (ICES, 2022).

Skates and rays in European waters are generally managed by a group-TAC, meaning several species are managed under a single Total Allowable Catch (TAC). In the North Sea this group-TAC applies to thornback ray (*Raja clavata*), blonde ray (*Raja brachyura*), spotted ray (*Raja montagui*) and cuckoo ray (*Leucoraja naevus*). Landings of starry ray (*Amblyraja radiata*) and common skate (*Dipturus sp.)* are prohibited. In the Netherlands, rays are mainly caught as by-catch in the mixed demersal fishery for flatfish (Van Overzee et al., 2014). For these species the rays below minimum landing size and catches that exceed weekly trip limits are discarded. Since 2019 this practice of discarding has been restricted for all quota regulated species, including rays, by the implementation of a landing obligation under the Common Fisheries Policy (European Union, 2013). The objective of the landing obligation is to create an incentive for fishers to avoid unwanted bycatches and thereby reduce discards rates. As a result of this legislation, fishermen will be forced to land all undersized, damaged and marketable fish of species under quota management, also referred to as a landing obligation (LO). This landing obligation allows exemptions for species which, according to the best available scientific advice, have a high survival probability when released into the sea, taking into account gear characteristics, fishing practices and the ecosystem. The European commission granted a temporary 'high survival' exemption for rays based on discards survival measurements in pulse trawl fisheries (Schram et al., 2018). The exemption will expire by 2023 and the European Commission indicated that for the exemption to be renewed or extended beyond 2023, knowledge gaps regarding discards survival probabilities of rays need to be filled.

The current study therefore aims to bridge the main gaps in our knowledge on the survival probability of rays when discarded by the most important Dutch demersal fisheries. We first selected the two most important species and demersal fisheries métiers based on amounts of discarded rays. Survival probabilities were then measured for each of these four species – métier combinations by captive observations.
This study is part of a larger project "Bridging knowledge gaps for sharks and rays" funded by the European Maritime and Fisheries Fund (EMFF).

2 Assignment

2.1 Objectives

The objective of this study was to measure survival probabilities of rays that are caught and discarded by the Dutch demersal fisheries in the North Sea and English Channel.

2.2 Phasing

Exploration of ray discards survival
It was not possible with the available time and resources to measure the survival probability for all ray species caught and discarded by every form of demersal fishery (métier) in the North Sea and English Channel. In this context, two métiers, tickler chain beam trawling and flyshooting, and two ray species, thornback and spotted ray, were selected based on the contributions of these species and métiers to the total amount of rays discarded by Dutch demersal fisheries.

Discards survival measurements
Discards survival probabilities were measured during five trips with a commercial beam trawler and four trips with a commercial flyshooter. During these trips researchers collected rays from the catches and housed them in on-board tank systems. Upon return in the harbor the rays were transported to the laboratory where their survival was monitored for another 21 days.

Dissemination and reporting
Includes all dissemination and reporting activities as foreseen in the project plan.

2.3 Products

The research into the survival probability of rays discarded by Dutch demersal fisheries resulted in the following products:

1. Report on the selection of ray species and demersal fisheries métiers for the survival probability experiments (Chapter 3)
2. Report on the discards survival experiments (Chapter 4)
3. Two articles on these studies in "Visserijnieuws".

This report covers both products 1 and 2.

3 Selection of ray species and demersal fisheries métiers for survival probability measurements

3.1 Introduction

We explored the condition and amounts in which ray species are discarded by the various Dutch demersal fisheries métiers. We also explored existing data on ray discards survival probabilities. The objective of these explorations was to make an informed selection of ray species and demersal fisheries métiers for which discards survival probabilities were going to be measured in the current project. The condition in which rays are discarded was assessed in five commercial fishing trips across demersal fisheries métiers. Amounts of discarded rays were assessed by analysing discards and landings data available in our databases. Existing data on ray survival probabilities were assessed by reviews of literature and the results of other completed or ongoing discards survival studies.

3.2 Materials and methods

3.2.1 Condition of discarded rays

The condition of discarded rays was assessed during five regular commercial fishing trips on a beam trawler (TBB, 3 trips), flyshooter (SSC, 1 trip) and twin-rigger (OTB, 1 trip). Detailed descriptions (in Dutch) of these métiers can be found here: Onderwijs Archive - Vistikhetmaar. All fishery operations during these trips were conducted in the southern North Sea according to commercial practices of the fishing vessels. Operational and environmental conditions during sea trips were recorded for each haul by the skippers on trawl lists (Table 1). Vessel and gear specifics are presented in Annex 1, Table 10 for TBB and OTB and in. Annex 1 Table 11 for SSC. Locations of sampled hauls are presented in Figure 1. Note that the three exploratory trips with the beam trawlers (vessels 2 and 3) were previously conducted in the framework of another project (Schram et al., 2020). The condition scoring of these previous trips are used in the current project to assess the vitality of the different ray species in beam trawlers.

Table 1: Conditions at sea during the exploration trips

Trip	Métier	Year	Month	Week	Mean water temp. (°C)	Wind speed range (Bft)	Mean wave height (m)	Mean catch processing (min)	Mean haul duration (min)	Mean fishing depth (m)
1	TBB	2018	Jun	23	-	2-4		12	97	24
2	TBB	2018	Jun	26	14.4	2-4	0.5	12.1	100	27
3	TBB	2018	Nov	47	-	4-8	1.7	12.3	147	43
4	OTB	2021	Jun	22	13.4	1-4	0.3	26	239	33
5	SSC	2021	Jun	25	-	0-4	0.8	17	78	36

Rays were sampled from the catches according to their availability at a maximum of 17 per haul to allow for condition assessment within 30 minutes after sampling. After sampling, fish were temporarily stored in 105L holding containers filled with seawater. Seawater in holding containers was regularly renewed to maintain sufficient (> 80% saturation) dissolved oxygen levels during storage. Once sampling of a haul had been completed, fish were sequentially taken from the holding containers for condition assessment, to measure total length (TL: in cm below) and to determine species and sex. The condition of individual rays was assessed by scoring vitality classes A to D, external damages and reflex impairments according to the flatfish protocol by Van der Reijden *et al.* (2017) that we modified for rays (Table 2). Upon completion of the assessment, rays were either returned to sea (discarded) or handed over to the vessel's crew to be landed as commercial catch.

Table 2: Description of criteria to score condition and determine vitality class of rays (modified for rays after Van der Reijden et al. (2017)).

Vitality class	
Class	Description
A	Fish lively, no visible or very minor external damages.
B	Fish less lively, minor scratches or discolorations on up to 20% of the dorsal skin surface area, some haemorrhaging on the ventral side, no or minor bruises on the ventral side.
C	Fish lethargic, intermediate scratches or discolorations on up to 50% of the dorsal skin surface area, several haemorrhaging and/or bruising on the ventral side.
D	Fish lethargic or dead, major scratches or discolorations on the dorsal skin surface area, significant haemorrhaging and/or bruising on the ventral side.
External damage scores	
Damage	Description (scoring: 1 = present; 0 = absent)
Wings	Wings are damaged or split.
Dorsal side	Damage to skin surface, scratches or discolorations at dorsal pigmented body surface.
Hypodermic haemorrhages	Superficial hypodermic haemorrhage on the ventral white body surface
Hypodermic bruises	Hypodermic purple-reddish bruise on the ventral white body surface
Intestines	Intestines are protruding or are visible through damaged body tissue of the fish.
Wound	A wound such that flesh is visible anywhere on the body including torn off thorns.
Reflex impairment scores	
Reflex	Description (1 = impaired; no (clear) response within 5 s of observation; 0 = unimpaired; obvious response within 5 s).
Wings	Ray is held out of the water, dorsal side up with one hand supporting the body at the head of the ray and the other hand supporting the body at the base of the tail. The ray actively flaps its pectoral fins (wings).
Eye retraction	While out of the water the ray is gently tapped on the head just behind the eyes with a blunt probe. The ray actively retracts its eyes.
Tail grab	While in the water resting on the tank bottom the ray is gently held by the tail. When the tail is gently pulled backwards, the ray struggles free and swims away (or attempts to do this).
Spiracles	While in the water resting on the tank bottom the movement of the spiracles is observed.

3.2.2 Landings and discards of rays

The amounts of rays discarded by various métiers and species was assessed by analysing discards and landings data available in WMR databases.

Discard data for thornback ray (*Raja clavata*), blonde ray (*Raja brachyura*) and spotted ray (*Raja montagui*) were retrieved from the Dutch discard monitoring program for the period 2018-2020. The program is mandated by the European Commission (EC) through the Data Collection Framework (DCF; EU 2016/1701, EU 2016/1251 and EU 2017/1004). In 2009, the Netherlands commenced a self-sampling programme in which discard data are collected for the Dutch bottom-trawl fisheries for a number of métiers, which are defined in the DCF based on gear type, target species assemblage, and mesh characteristics. In total, 167, 158 and 164 self-sampling trips were carried out in 2018, 2019 and 2020. During each self-sampling trip, discards samples (80kg) were collected from two hauls and taken to the laboratory for analysis of species composition. The collected data were raised from haul to trip level and finally to fleet level to estimate total discards by species for the Dutch demersal fleet by métier (Bleeker *et al.,* 2022). For the three ray species, average discards (kg and numbers) per trip in 2018-2020 were calculated on trip level and averaged over total trips per quarter and métier (beam trawls or other bottom trawls). Landing data for thornback ray, blonde ray, and spotted ray in beam trawl, flyshoot, twinrig and quadrig fisheries in ICES subareas 4 (North Sea) and division 7d (Eastern Channel) were obtained for the years 2018-2020 from logbook data of the Dutch fisheries.

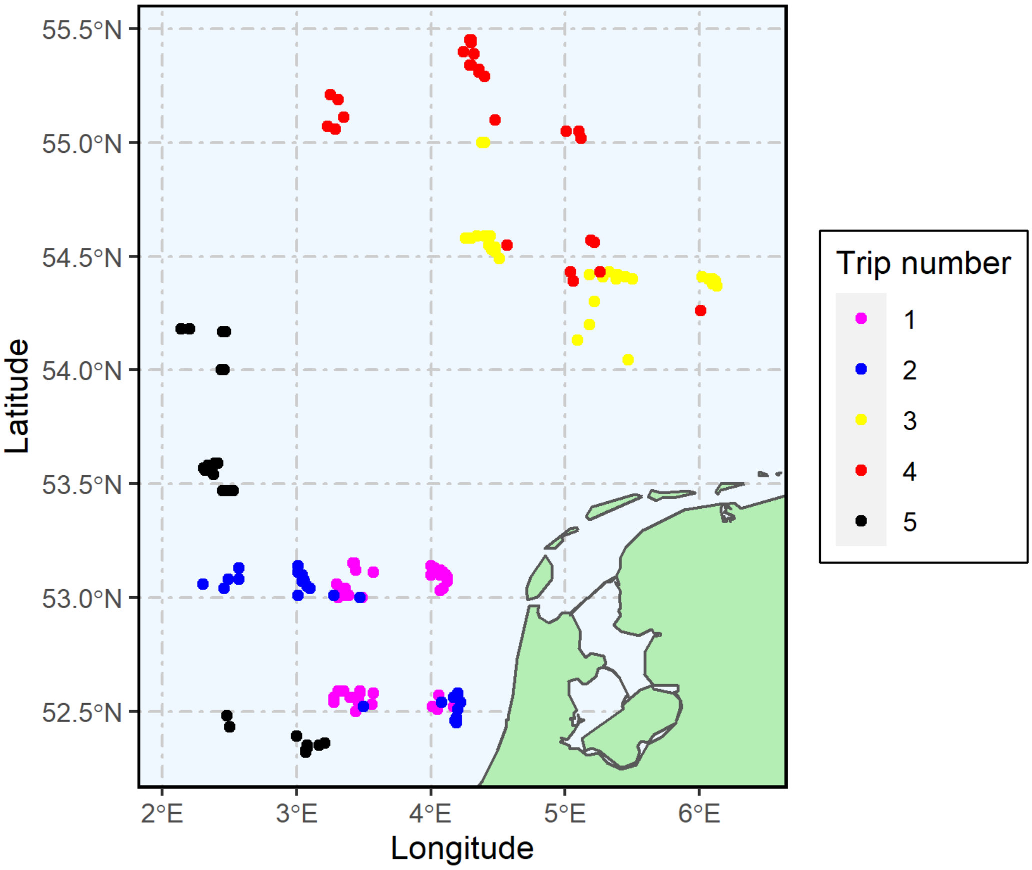

Figure 1: Locations of sampled hauls per exploration trip.

3.2.3 Other discards survival studies

Scientific literature on ray discards survival and results of recently completed and ongoing other relevant studies were assessed by literature research and by utilizing our international scientific network. Other studies were deemed relevant in case they used captive observation to determine discards survival probabilities of ray species caught in European waters by demersal fisheries. We excluded studies based on vitality assessments because although vitality is a useful indicator for ray discards survival (Enever et al., 2009) it does not quantify survival probability.

3.3 Results

3.3.1 Condition of discarded rays

A total of 333 rays were sampled and assessed during the exploratory trips representing five species: thornback ray (RJC), blonde ray (RJH), spotted ray (RJM), cuckoo ray (RJN) and starry ray (RJR). Sampled numbers per species and métier are presented in Table 3. Note that during beam trawl (TBB) trips only thornback and spotted ray were sampled (Schram et al., 2020). Within métiers, none of the species was clearly more vulnerable or more robust than any of the other sampled species. Within species, none of the métiers was clearly more detrimental to ray condition (Figure 2).

Table 3: Number observations per species during the exploration trips.

Trip	Métier	RJC	RJH	RJM	RJN	RJR
1-3	TBB	47	n.s.	62	n.s.	n.s.
4	OTB	26	6	87	12	64
5	SSC	26	1	2	n.p.	n.p.

n.s. = not sampled; n.p. = not present

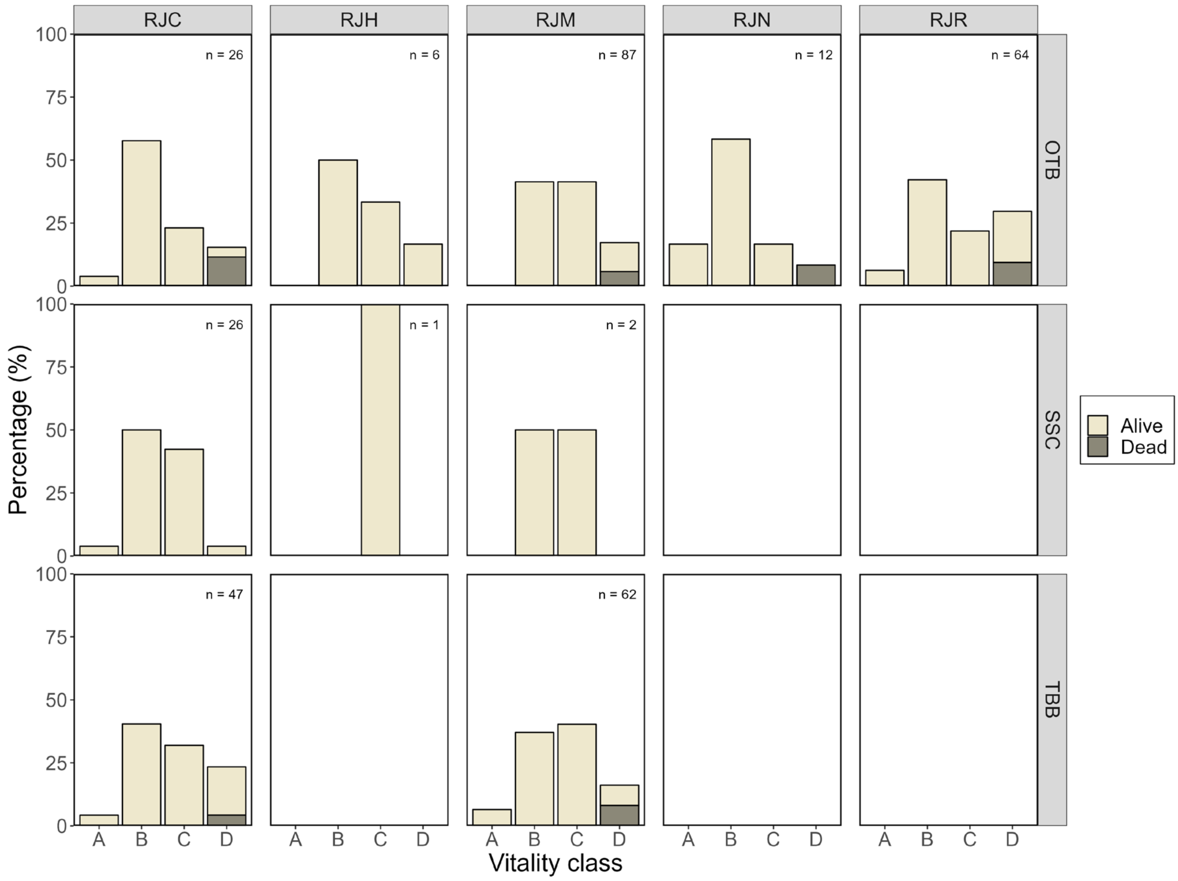

Figure 2: Relative distribution of vitality classes for rays discarded by beam trawl (TBB), flyshoot (SSC) and twinrig (OTB) fisheries. RJC = thornback ray, RJH = blonde ray, RJM = spotted ray, RJN = cuckoo ray, RJR = starry ray.

3.3.2 Ray discards data

The Dutch discards monitoring program reports the presence of thornback, spotted, blonde, cuckoo and starry ray in the discards of Dutch beam trawl and other bottom trawl fisheries including twin and quad rigging (Figure 3). For flyshoot fisheries no discards data are available. Beam trawlers discard more rays per trip than twin-rig and quad-rig otter trawlers together and the majority of discarded rays are thornback and spotted rays. Note that estimated discards may be uncertain because elasmobranchs are mostly bycatch in all types of fisheries and national sampling effort might be insufficient for estimating precise and unbiased discards for elasmobranchs (ICES, 2017; 2022). Consequently, discard data of rays have not generally been used in the evaluation of stock status.

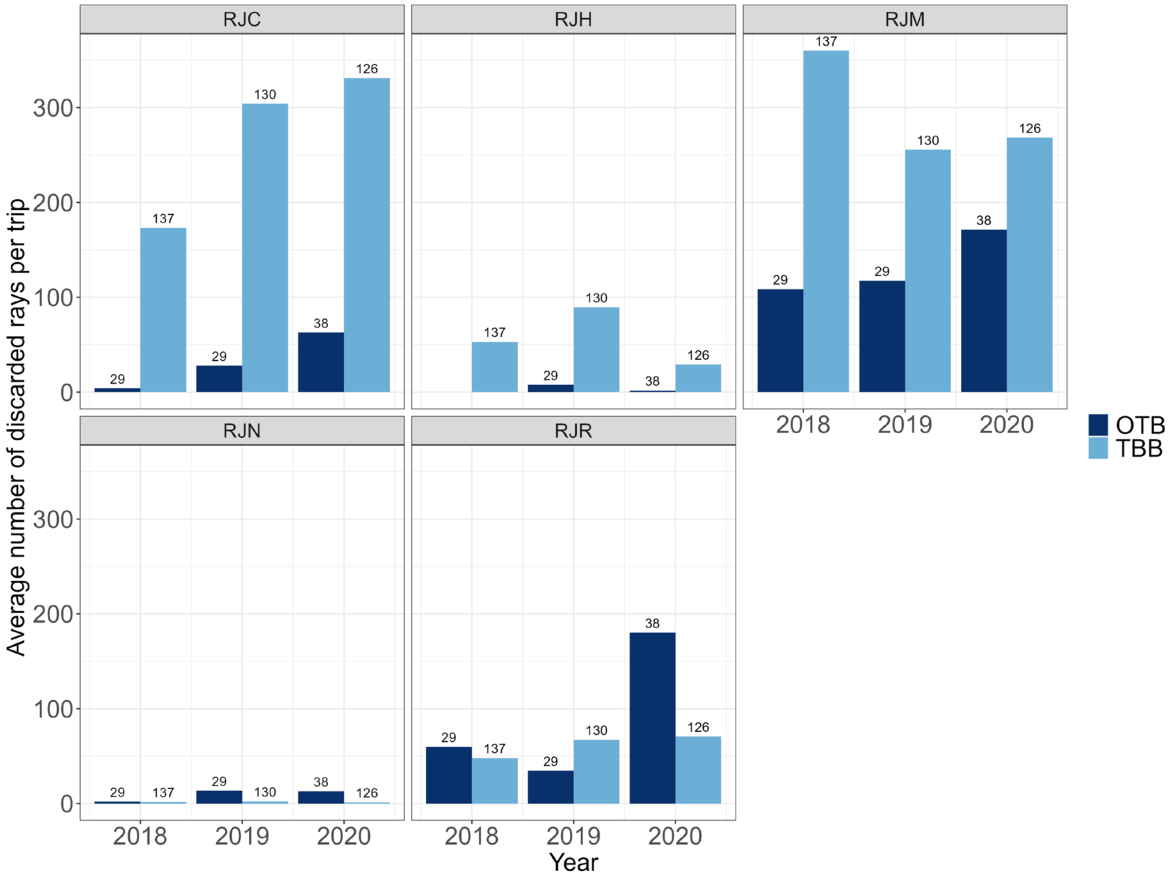

Figure 3: Ray discarding expressed as average number of discarded rays per trip in 2018-2020 for thornback ray (RJC), blond ray (RJH), spotted ray (RJM), cuckoo ray (RJN) and starry ray (RJR) by beam trawls (TBB) and other bottom trawls (OTB). Total number of sampled trips are noted on top of each bar.

3.3.3 Ray landing data

Beam trawling is by far the main contributor to ray landings by Dutch demersal fisheries, followed by flyshoot fisheries and twin-rig otter trawling (Figure 4). Landings by twin-rig otter trawlers exceed landings by flyshoot fisheries in the North Sea. However, flyshoot landings mainly originated from fisheries in the Eastern Channel and landings from the North Sea and Eastern Channel combined exceed landings realized by twin-rig otter trawlers. Thornback ray is the main species landed, followed by spotted ray and blonde ray (Figure 4). There are almost no landings of cuckoo ray due to their small body size and landings of starry ray are prohibited and these species consequently do not appear in landing data. Assuming that ray landing data are indicative for the amounts of ray discards, the métiers beam trawling and flyshoot fisheries discard the largest amounts of rays with thornback and spotted ray as dominant species. For beam trawling these findings are in agreement with the results that appeared from discards data (see 3.3.2). For flyshoot this cross-check cannot be made due to the absence of discards data.

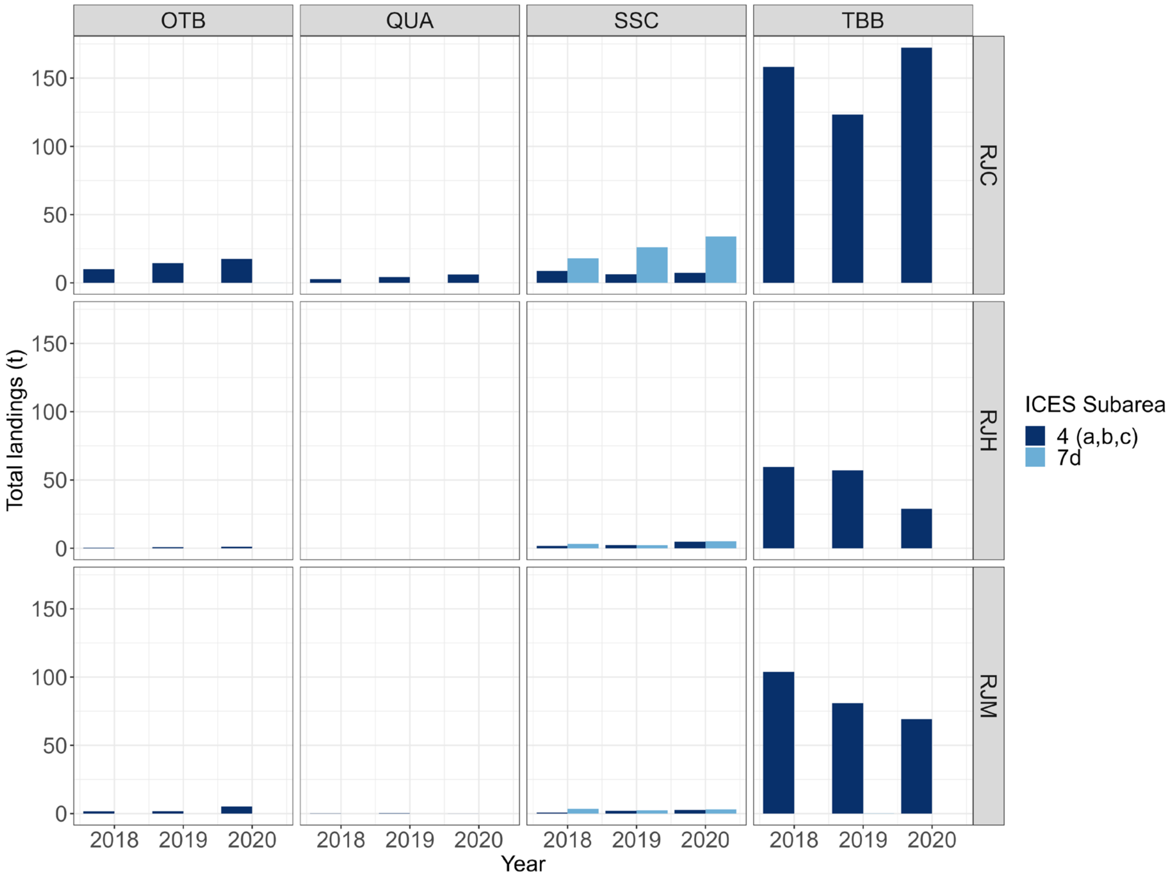

Figure 4: Total ray landings by Dutch demersal fisheries per métier and species in ICES subareas 4 (North sea) and division 7d (Eastern Channel). TBB = beam trawling, SSC = flyshoot, OTB = twin-rigged otter trawling, QU = quad-rigged otter trawling. RJC = thornback ray, RJH = blonde ray, RJM = spotted ray.

3.3.4 Other discards survival studies

Table 4 provides an overview of survival studies using captive observation for rays discarded by demersal fisheries in European waters. Most studies apply rather short monitoring periods of 2 to 5 days while post capture mortality among rays may take up to two to three weeks to level out (Schram and Molenaar, 2018). It is therefore likely that these studies report underestimates of the actual survival probability. Only two studies apply monitoring periods that were in our opinion sufficiently long: the INTERREG 2-Seas SUMARiS (Sustainable Management of Rays and Skates) project (Van Bogaert et al., 2020) and our own previous work in pulse beam trawling. In the SUMARiS project sample sizes for measurements in beam and otter trawling were rather low with 2 to 71 specimens per species (Table 4), Van Bogaert et al., 2020). (Table 4). Our own work on discards survival concerned thornback and spotted ray in pulse trawl fisheries (Schram and Molenaar, 2018). In that study monitoring of survival in captivity of 99 thornback rays collected during nine trips spread out over the year yielded an overall survival probability of 53%. Although condition assessments of thornback rays caught by tickler chain beam trawlers did not indicate a lower survival probability than measured for pulse trawling (Schram et al., 2020), the survival probability measured in pulse trawling for thornback ray may not be representative for beam trawling with tickler chains because it probably exerts a higher mechanical impact on the fish compared to pulse trawling due to the higher towing speed and heavier fishing gear. Mechanical impact is a main cause for discards mortality (Davis, 2002; Veldhuizen et al., 2018; Cook et al., 2019). For spotted rays the sample size was too low (n=23) for a reliable estimate of survival probability. For flyshoot fisheries no studies on ray discards survival have been published.

Table 4: Published records of survival probabilities of rays in demersal fisheries measured by monitoring in captivity. .

Species	Gear	Area	Monitoring duration (d)	N	Survival (%)	Reference
Blonde ray	OTB	Bristol Channel	3	11	55	Enever et al., (2009)
	OTB	North Sea; English Channel	21	37	87	Van Bogaert et al., (2020)
	TBB	North Sea; English Channel	21	20	70.5	Van Bogaert et al., (2020)
Cuckoo ray	OTB	Bristol Channel	3	6	33	Enever et al., (2009)
	TBB, (0.5 h tows)	Irish Sea	5	32	59	Kaiser and Spencer, (1995)
Small eyed ray	OTB	Bristol Channel	3	39	51	Enever et al., (2009)
	OTB	Bristol Channel	2		55-67	Enever et al., (2010)
Spotted ray	OTB	North Sea; English Channel	21	2	100	Van Bogaert et al., (2020)
	TBB	North Sea; English Channel	21	25	27.5	Van Bogaert et al., (2020)
	TBB (pulse)	North Sea	21	23	21 -67	Schram and Molenaar (2018)
Thornback ray	OTB	Bristol Channel	3	68	59	Enever et al., 2009
	OTB	North Sea; English Channel	21	71	76.5	Van Bogaert et al., (2020)
	OTB	Western Mediterranean Sea	2	120	81	Saygu and Deval (2014)
	TBB	North Sea; English Channel	21	21	56.9	Van Bogaert et al., (2020)
	TBB (pulse)	North Sea	21	99	53	Schram and Molenaar (2018)
Undulate ray	OTB	North Sea; English Channel	21	5	26.4	Van Bogaert et al., (2020)
	TBB	North Sea; English Channel	21	27	64.4	Van Bogaert et al., (2020)
Rajidae	TBB	North Sea	2-3	249	72	Depestele et al., (2014)

3.4 Synthesis: selection of species and métiers for discards survival experiments

We selected beam trawl and flyshoot fisheries as the métiers and thornback and spotted rays as the species for the discards survival experiments for the following reasons:

1. Beam trawl fisheries is quantitatively by far the main contributor to ray discarding and landings by Dutch demersal fisheries;
2. Discards survival of spotted and thornback rays has been studied for beam trawling (SUMARIS project) but because of the low number of observations it is not evident that the result of the SUMARIS project are sufficient to support an exemption to the landing obligation. Therefore, including survival measurements for beam trawling in this project is deemed necessary.

3. Flyshoot fisheries is the second main contributor to ray landings by Dutch demersal fisheries, closely followed by twin-rigged otter trawl fisheries;
4. Discards survival of rays has not been studied for flyshoot fisheries while for twin-rigged otter trawl fisheries the SUMARIS project collected a reasonable number of observations on discards survival of mainly thornback rays.
5. Thornback and spotted rays are quantitatively the main discarded species by Dutch demersal fisheries;

It should be noted that the condition assessment of rays caught by different demersal fisheries métiers did not highlight exceptionally vulnerable or robust species or detrimental métiers. Based on the condition assessment none of the species–métier combinations was expected to have either exceptionally low or high discards survival probability. Therefore the results of the condition assessments were not considered in the selection of species and métiers for the survival experiments.

4 Survival probability of thornback and spotted rays discarded by beam trawl and flyshoot fisheries

4.1 Introduction

The exploration of discarding of rays by Dutch demersal fisheries highlighted beam trawling and flyshoot fisheries as the métiers that discard most rays with thornback and spotted rays as dominant species. Consequently these métiers and species were selected for discards survival probability measurements. Survival probabilities were measured by sampling rays from commercial catches and monitoring their post-capture survival for up to 25 days.

4.2 Materials and methods

4.2.1 Ethics statements

The treatment of the fish was in accordance with the Dutch animal experimentation act, as approved by ethical committees (Experiments 2018.D-0002.004 and 2021.D-0007.001). The methodology was in accordance with the guidelines for discards survival studies developed by the Workshop on Methods for Estimating Discard Survival (WKMEDS) of the International Council for the Exploration of the Sea (ICES) (Breen and Catchpole, 2021). Release of surviving rays to the Eastern Scheldt after the completion of experiments was in accordance with IUCN (International Union for Conservation of Nature) Guidelines for reintroductions and other conservation translocations (IUCN/SSC, 2013).

4.2.2 Experiments

4.2.2.1 Trips

Test-fish were collected during nine regular commercial fishing trips on a commercial beam trawler (TBB, 5 trips, Vessel 4 in Table 2) and a commercial flyshooter (SSC, 4 trips, Vessel 6 in Table 3). All trips lasted between four and five days, comparable to commercial trip lengths. All fishery operations were conducted in the southern North Sea and the English Channel (Figure 7) according to commercial practices of the fishing vessels. Trips were spread out over the year (Table 6) to account for the potential effect of variable environmental and fishing conditions on discards survival (Van der Reijden et al., 2017; Schram et al., 2019). Operational and environmental conditions during sea trips were recorded for each haul by the skippers on trawl lists provided by the researchers. Average values per trip are presented in Table 6.

4.2.2.2 Test-fish sampling

In total 485 test-fish were sampled with thornback rays ranging from 19 to 92 cm and spotted rays ranging from 24 to 63 cm total length (TL, Figure 5). All rays were sampled during the semi-automatic catch-sorting process which is common in these fisheries (Figure 6). In this process, catches were discharged from the cod-end(s) into one (flyshoot) or two (beam trawl) hoppers. From the hoppers, the catches were flushed into a central pit from which the catch was transported by a conveyer belt onto the sorting belt. Marketable fish were manually collected from the sorting belt by crew members. At the end of the sorting belt, the remaining unwanted catch, including fish with no commercial value and undersized fish, dropped into a gutter with a water supply that discharges the catch back into the sea.
Per trip a total of 40 small rays (< 65 cm TL) and 6 large rays (> 65 cm TL) could be sampled given the number of tanks in the on-board monitoring units (see below). We aimed to sample 20 thornback and 20 spotted rays smaller than 65 cm TL each trip by sampling five rays from four hauls for both species.

Each sampled haul we aimed to sample the first two (C1) and last three (C3) rays per species that appeared on the sorting belt to account for the potential effect of time spent in catch processing on survival probability. Occasionally, rays were sampled from the mid part of catch processing (C2) to obtain the desired sample size per haul. For each sampled haul the start and end time of catch sorting were recorded to obtain the approximate sampling time of individual rays. Each trip large thornback rays (> 65 cm TL) were opportunistically sampled according to their availability in catches and on board housing capacity. Spotted rays > 65 cm TL were not available in any of the sampled hauls. Low numbers of rays in some of the catches incidentally forced us to deviate from this sampling scheme in terms of numbers per haul and species sampled. Rays that were dead when sampled or died at sea, and housing of two small rays (< 25 cm) in one tank gave opportunities to sample more rays per trip. Actual numbers of rays sampled per species and trip are given in Table 8.

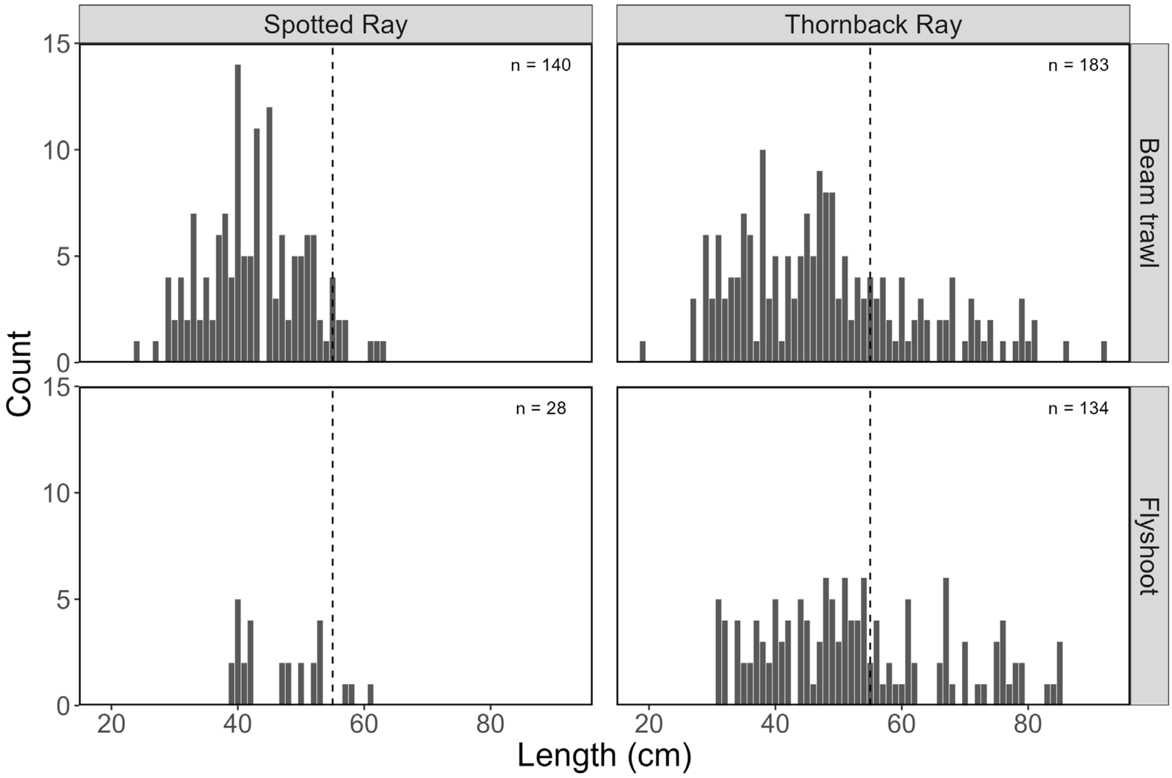

Figure 5: Length-frequency distributions per species and métier for the test-fish sampled for discards survival probability measurements. Horizontal dashed lines indicate the minimum landing size (55 cm).

4.2.2.3 Control fish

During all trips, control fish of the same species (n = 4 per species) were used to separate potential effects of the experimental procedures on mortality from fisheries-induced mortality. At the start of a trip, control fish were stored on deck in aerated 600L tanks. At sea the tank water was regularly renewed with surface seawater. Control fish were exposed to the exact same experimental procedures throughout the experiments as test-fish as of the moment of test-fish collection from the sorting belt. Control fish were obtained by collecting least damaged rays from the catches of a research vessel and by using test-fish from previous trips as control fish. Prior to their use in experimental trips, control fish were stored in tanks placed in a climate controlled room for at least three weeks. During this period, fisheries-induced mortality levelled out while surviving fish could recover from injuries and regain good condition. During storage, fish were fed daily with dead, uncooked brown shrimps (*Crangon crangon*) and pieces of herring (*Clupea harengus*) and Atlantic mackerel (*Scomber scombrus*) to visually observed satiation. Only fish in visually observed good condition, well-fed and without visible injuries, were used as control fish.

4.2.2.4 Initial assessment after sampling

After sampling from catches, fish were temporarily stored in 105L holding containers filled with seawater. Seawater in holding containers was regularly renewed to maintain dissolved oxygen levels during storage. Once sampling of a haul had been completed, fish were sequentially taken from the holding containers for condition assessment, to measure total length (TL: in cm below), to determine their sex and for tagging. Fish condition of each individual fish was determined and scored A to D by scoring reflex impairment and damages (Table 2). Fish were tagged with Trovan Unique glass transponders (type ID100) to allow for identification of individuals. Transponders were injected subcutaneously at the base of the tail using an IID100E injector.

Table 5: Conditions during the sea trips.

Trip	Métier	Year	Month	Week	Mean water temp. (°C)	Wind speed range (Bft)	Mean wave height (m)	Mean catch processing (min)	Mean haul duration (min)	Mean fishing depth (m)
1	TBB	2021	Oct	41		3-4	1.14	17	126	27
2	SSC	2021	Nov	47	13.5	2-5	1.1	44	88	32
3	TBB	2022	Jan	3	8.7	1-4	1.7	28	126	28
4	SSC	2022	Mar	13	10.0	2-4	1.3	24	69	45
5	TBB	2022	May	19	11.3	1-4	0.7	24	124	27
6	SSC	2022	Jun	24	16.0	1-4	0.5	26	67	38
7	TBB	2022	Jun	26	15.6	1-3		23	124	27
8	SSC	2022	Aug	33	20.2	0-4	1.0	24	67	37
9	TBB	2022	Sep	38	18.1	1-6	0.9	24	121	26

4.2.2.5 Experimental facilities

All test-fish and control fish were housed in four custom-built monitoring units installed on board. Three units consisted of a stainless steel framework holding 16 24L tanks (60 cm L x 40 cm W x 12 cm H), resulting in a total capacity of 48 tanks on a vessel to house 48 rays with a total length < 65 cm. The fourth unit held six 84 L tanks (80 cm L x 60 cm W x 17.5 cm H) to house six rays with a total length > 65 cm. Each tank was equipped with an individual water supply. A pump with a water intake approximately 2 meters below sea surface continuously supplied seawater to the tanks. Water flow rates were approximately two tank volumes per hour to maintain proper water quality. Tanks were covered with transparent lids to limit water loss by sloshing while allowing for visual inspection of fish. Upon return in port, the units were transported to the laboratory in a temperature controlled truck. Transport time ranged from one to three hours depending on the home port of the vessel. During transport each unit was placed inside a tank that was partly filled with seawater and equipped with a submerged pump to supply water to each fish tank in the unit. Fish tanks discharged their effluents in the tank in which the unit was placed, allowing for recirculation and aeration of the water. Upon arrival at the laboratory, fish were removed from their tanks and housed in a raceway system placed in a temperature controlled room. The raceway system consisted of 12 tanks, each with a bottom surface area of 2.5 m^2 and a water volume of 500 L (2.5 m L x 1 m W x 25 cm H). Maximum fish density was 4 fish per tank (1.6 m^2/fish) for rays > 65 cm TL and 8 fish per tank (0.8 m^2/fish) for rays < 65 cm TL. Control fish were mixed with test fish. Different species were housed in separate tanks. Water temperature was set at the North Sea surface water temperature at time of fish collection. All tanks were connected to a single water recirculation system consisting of a pumping tank, a 420 L moving bed bioreactor (MBBR, filled with 200 L of filter beads) a 600 L trickling filter and a 80 W UV filter. Water in the system was continuously renewed with filtered seawater from the Eastern Scheldt at a rate of 2 to 3 m^3/d. In the laboratory, all tanks were supplied with coarse sand as bottom substrate and fish were fed daily to visually observed satiation with uncooked brown shrimps (*Crangon crangon*) and pieces of herring (*Clupea harengus*) and

Atlantic mackerel (*Scomber scombrus*) fish. Dissolved oxygen concentration and water temperature were measured (Hach Lange Multimeter).

4.2.2.6 Monitoring of survival

Upon completion of their initial assessment, live rays were individually placed in 24 L tanks (TL < 65 cm) or 84 L tanks (TL > 65 cm) (see 4.2.2.5 Experimental facilities). Occasionally two small specimens (TL < 25 cm) were placed in a single 24 L tank that was split into two equally sized compartments by a perforated plexiglass sheet. Fish that were considered dead when sampled (no spiracle movement for more than 15 seconds) were recorded as dead at time zero and not placed in tanks. All tanks were inspected for mortalities every 12 hours on board and every 24 hours in the laboratory. Dead fish were detected by visual confirmation of the absence of spiracle movement, immediately removed from their tanks and identified by their PIT tags. The date and time at which a ray was found dead was recorded. Lethargic fish were not removed as for their potential recovery and to obtain actual survival time. Dissolved oxygen concentration and water temperature were measured (Hach Lange Multimeter). Water flows to individual tanks were increased if oxygen saturation was below 80%. In the laboratory rays were monitored for 21 days. Maximum monitoring time ranged from 22 to 25 days for surviving individual rays depending on the day of their sampling at sea.

4.2.2.7 Termination of experiments

All experiments were terminated after 21 days of survival monitoring in the laboratory. Upon termination of the experiment all surviving rays were netted from the tanks and identified by their PIT tags to record their condition (Table 4), species, total length (TL: in cm below) and sex. Damage to skin surface, scratches or discolorations at dorsal pigmented body surface were recorded as 'absent' in case these were previously sustained and clearly healed. After completion of all experimental procedures for a single discard survival experiment, the surviving rays were either released to the Eastern Scheldt or kept in captivity for use as control fish in upcoming survival experiments. After termination of the ninth and last experiment, all surviving rays were released.

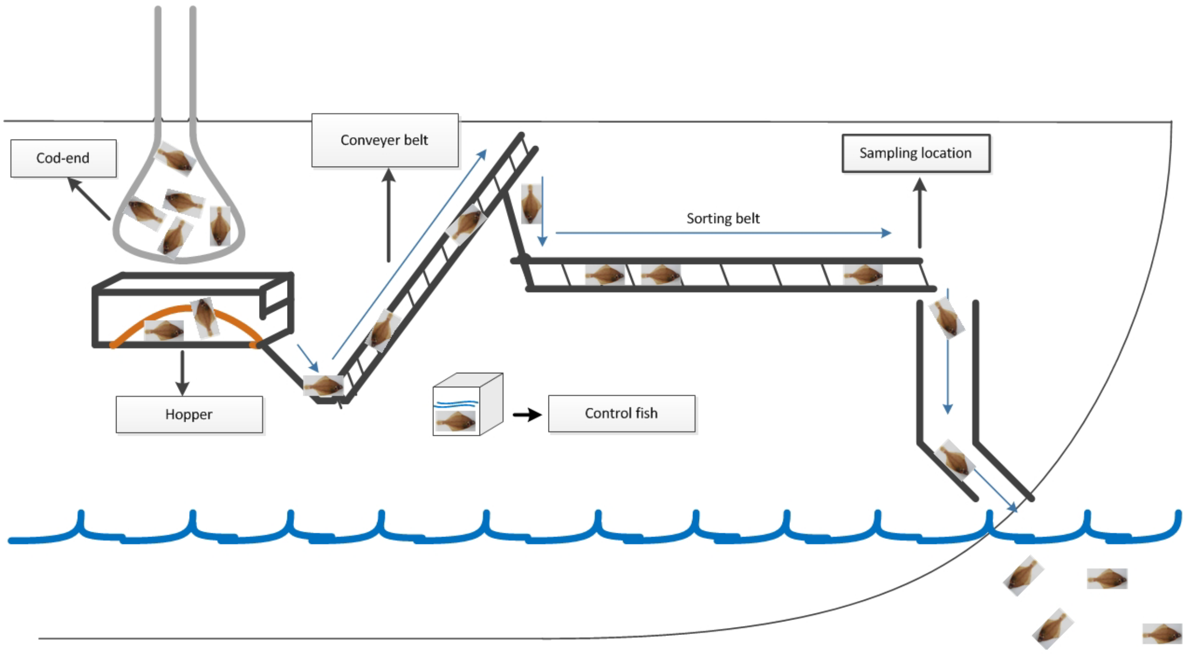

Figure 6: Schematic drawing of semi-automatic catch processing line on board of a beam trawler and flyshooter. All fish collected from the catch for the survival experiment are collected at the location marked with 'sampling location'.

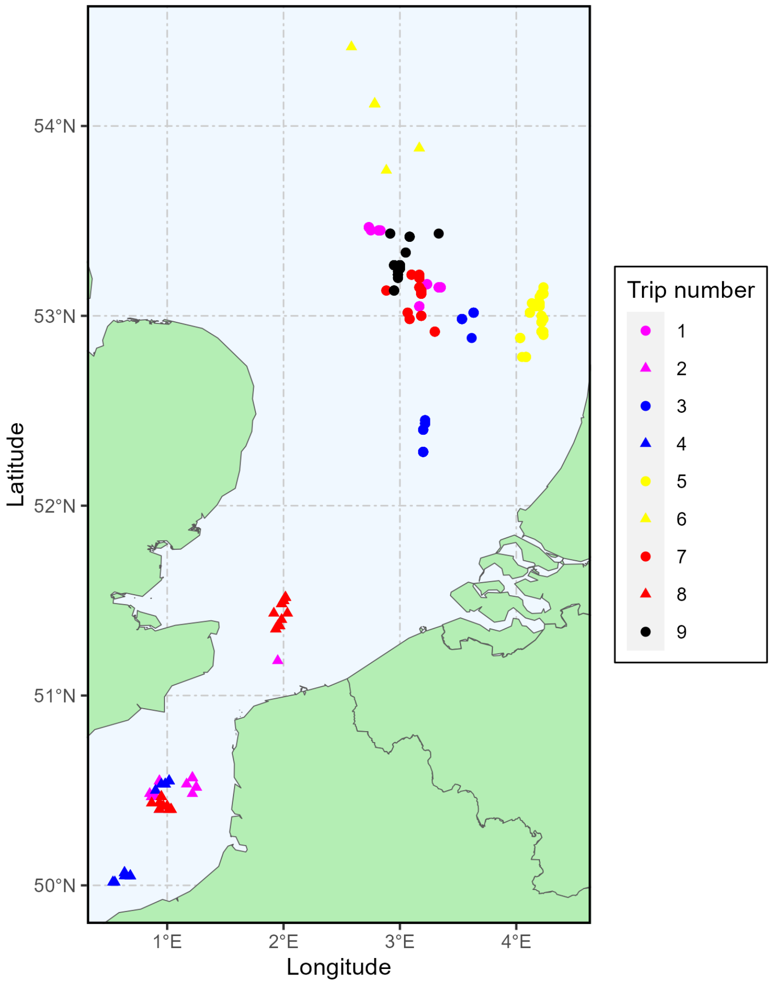

Figure 7: Locations in southern North Sea and English Channel of sampled hauls per discards survival trip (circles are TBB trips, triangles are SCC trips).

Table 6: Numbers of rays sampled per trip.

Trip	Métier	Thornback ray					Spotted ray				
		Start[1]	Mid[2]	End[3]	Total	Ctrl[4]	Start[1]	Mid[2]	End[3]	Total	Ctrl[4]
1	TBB	11	0	18	29	4	12	2	15	29	4
2	SSC	23	7	16	46	4	-	-	-	-	-
3	TBB	15	0	14	29	4	16	-	6	22	4
4	SSC	6	0	26	32	4	-	-	1	1	4
5	TBB	28	1	18	47	5	9	1	7	17	3
6	SSC	1	0	0	1	4	8	1	6	15	4
7	TBB	15	1	20	36	4	10	1	17	28	4
8	SSC	17	0	38	55	4	5	-	7	12	4
9	TBB	27	0	15	42	4	23	-	21	44	4
Total	TBB	96	2	85	183	21	70	4	66	140	19
Total	SSC	47	7	80	134	16	13	1	14	28	12
Total	All	143	9	165	317	37	83	5	80	168	31

1) Start of the catch sorting process; 2) Mid of the catch sorting process; 3) End of the catch sorting process; 4) Ctrl = Control fish

4.2.3 Data analysis

4.2.3.1 Data management

During and after each trip, the data for that trip was entered into excel files of the trawl list, the initial assessment after sampling and the registration of mortality. All these data were joined in a file for each trip where each entry represented a sampled fish. These files were combined in a single overall file containing all data. Fish that died due to unnatural causes, mainly by jumping from the containment tank, were censored: This means that rather than being registered as dead, their experiment was said to have been terminated at the time of death.

4.2.3.2 Survival curves

To visualise and analyse the survival of the sampled fish, the R-package *survival* was used. Using the function *survfit*, Kaplan-Meier survival curves (Kaplan and Meier, 2012) were fitted and 95% Confidence Intervals were computed. Survival curves were created for:

- Control fish vs. test-fish for both gears and species
- All trips as separate curves for both species
- Above (≥ 55 cm) vs below minimum landing size for both gears and species
- The different condition classes for both gears and species

For all plots, except for the plot displaying the survival for both species during each trip individually, the 95% Confidence Intervals computed by the *survfit*-function were plotted.

4.2.3.3 Statistical tests survival

To test if certain differences in survival were significant, the functions *survdiff* and *pairwise_survdiff* from the *survival* package was used, which implements the G-rho family of Harrington and Fleming (1982). For this test, a X^2 statistic is computed to test if the survival of a set of sampled populations can be considered significantly different or not. This was done for the following populations:

- Spotted ray: TBB vs. SSC
- Thornback ray: TBB vs SSC
- Spotted ray in TBB: below vs. above minimum landing size
- Spotted ray in SSC: below vs. above minimum landing size
- Thornback ray in TBB: below vs. above minimum landing size
- Thornback ray in SSC: below vs. above minimum landing size
- Spotted ray in TBB: different vitality classes (A vs. B vs. C vs. D)
- Spotted ray in SSC: different vitality classes (A vs. B vs. C vs. D)
- Thornback ray in TBB: different vitality classes (A vs. B vs. C vs. D)
- Thornback ray in SSC: different vitality n classes (A vs. B vs. C vs. D)

These tests compute a p-value, and the difference in survival was deemed significant when $p < 0.05$.

4.2.3.4 Vitality classes

To test if the distribution amongst the vitality classes differed significantly between the gear types (for spotted and thornback rays separately), Wilcoxon Rank Sum Tests were used on the numerical vitality data (where A =1, B = 2, etc.).

4.2.3.5 Predictors of mortality

Generalized Linear Mixed-Effect Models (GLMMs) were computed to identify the combination of variables that best explained the variation in mortality. In these models, fish were grouped into hauls. Using the *dredge* function from the *MuMIn* package in R, models were computed of all combinations of the explaining variables length, haul duration, processing time, sea surface temperature, depth, wind speed, gear, species, and the interaction effects between gear and processing time and haul duration. The minimum number of included (interaction) effects was one and the maximum six. The numerical variables were normalized to increase the performance of the models. The models with the best fit were identified by comparing AIC values. Using the *plot_model* function in the *plot_model* package, we plotted the predicted probabilities of a fish not surviving until the end of the experiment as a function of the selected fixed effects.

4.3 Results

4.3.1 Survival probabilities of rays discarded by beam trawl fisheries

For beam trawl fisheries the overall discards survival probability estimates are 45.5% (95% confidence interval 37.9%-54.5%) for spotted ray and 49.6% (95% confidence interval 42.9%-57.4%) for thornback ray (Figure 8 top panel, Table 7). These estimates are based on five trips spread out over the year and conducted under variable environmental conditions (Table 5). Survival of control fish was 100% for both species (Figure 8a-b). Most of the mortality among spotted rays occurred within the first five days of the experiment while mortality among thornback rays occurred up to approximately day 20 and levelled out thereafter (Figure 8a-b). Direct mortality, i.e. dead at sampling, was 11.3% for spotted ray and 11.8% for thornback ray. For spotted ray all except trip 1 yielded very similar survival probability estimates, i.e. a fairly constant survival of approximately 40% throughout the year. For thornback ray much more variation in discards survival was observed among trips (Figure 8c-d). For both species no difference in discards survival estimates were observed for rays < 55 cm (below the current minimum landing size) and rays ≥ 55 cm (Figure 8e-f, Table 8).

Table 7: Overall discards survival probability estimates (%) and their 95% confidence intervals for spotted and thornback ray discarded by beam trawl (TBB) and flyshoot (SSC). Note that no comparisons between species were made.

Survival prob. (95% CI)	TBB	n	SSC	n	Significant? (p-value)
Spotted ray	45.5% (37.9-54.5)	140	77.6% (63.3-95.2)	28	Yes (p = 0.01)
Thornback ray	49.6% (42.9-57.4)	183	81.0% (74.4-88.2)	134	Yes (p << 0.001)

4.3.2 Survival probabilities of rays discarded by flyshoot fisheries

For flyshoot fisheries the overall discards survival probability estimates are 77.6% (95% confidence interval 63.3%-95.2%) for spotted ray and 81.0% (95% confidence interval 74.4%-88.2%) for thornback ray (Figure 9a-b, Table 7). These estimates are based on four trips spread out over the year and conducted under variable environmental conditions (Table 5). Note that for spotted ray the number of observations is small (n = 25). Survival of control fish was 100% for both species (Figure 9a-b). All mortality among spotted rays occurred within the first two days of the experiment while mortality among thornback rays occurs up to approximately day 10 and levels out thereafter (Figure 9a-b). Direct mortality, i.e. dead at sampling, was 2.5% for spotted ray and 4.0% for thornback ray. For both spotted and thornback ray the four trips show some variation in discards survival estimated (Figure 9c-d). No difference in discards survival probability estimates were observed for thornback rays < 55 cm (below the current minimum landing size) and rays ≥ 55 cm (Figure 9e-f, Table 8). For spotted ray the sample size of especially rays ≥ 55 cm is considered too small to evaluate the effect of size class on survival probability.

Table 8: Overall discards survival probability estimates (%) and their 95% confidence intervals for spotted and thornback ray discarded by beam trawl (TBB) and flyshoot (SSC) fisheries for the size classes below (<55 cm) and above (≥ 55 cm) current minimum landing. Note that no comparisons between species were made.

Survival prob. (95% CI)	Gear	Below min. landing size	n	Min. landing size and above	n	Significant? (p-value)
Spotted ray	TBB	44.7% (36.9-54.2)	129	54.5% (31.8-93.6)	11	No (p = 0.5)
	SSC	75.4% (60.1-94.6)	25	100% (100-100)	3	No (p = 0.4)
Thornback ray	TBB	51.5% (43.6-60.8)	130	45.3% (33.7-60.9)	53	No (p = 0.7)
	SSC	80.5% (72.4-89.6)	85	82.1% (71.5-94.3)	49	No (p = 0.9)

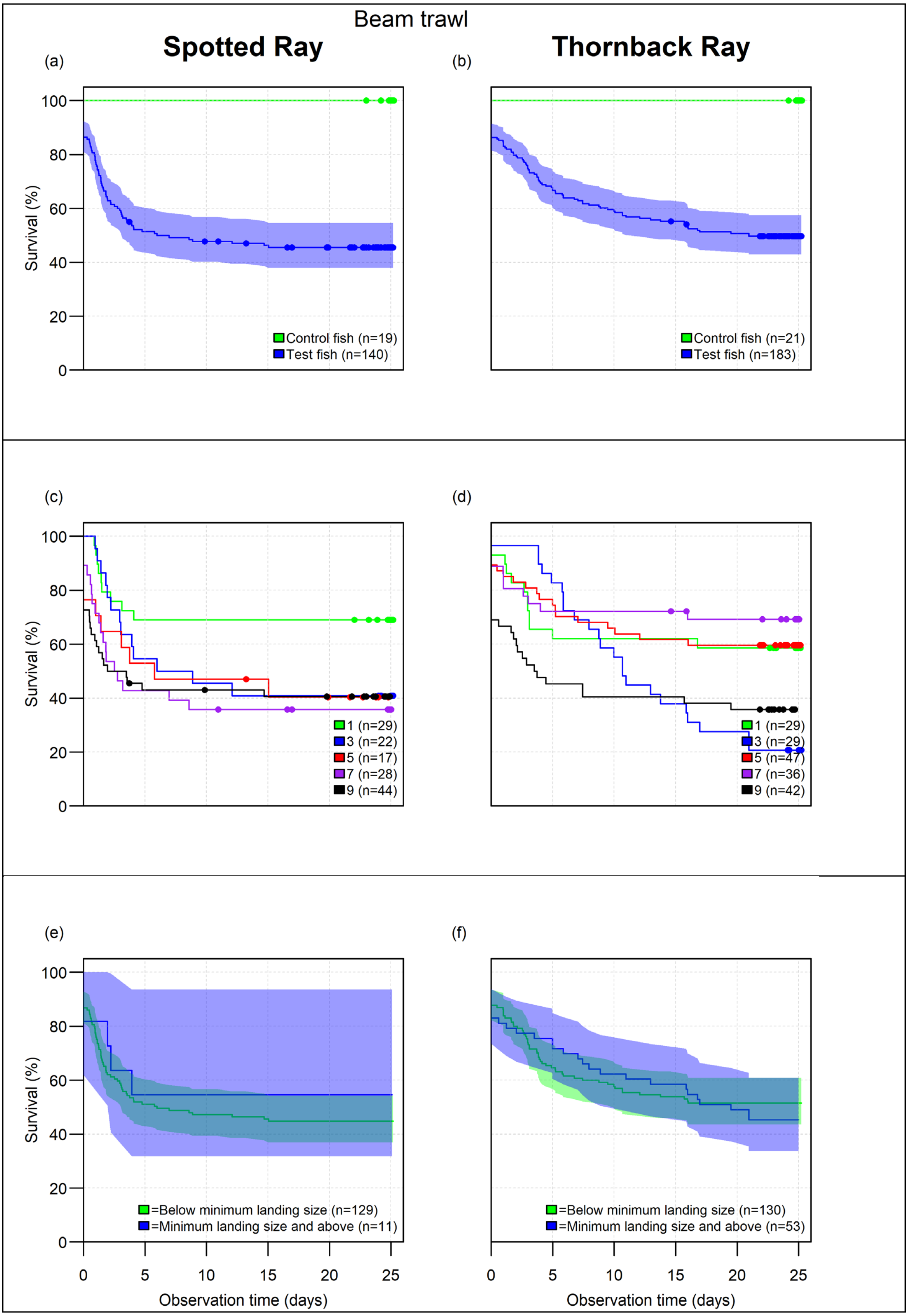

Figure 8: Kaplan-Meier survival curves for spotted (left) and thornback ray (right) discarded by beam trawl fisheries (TBB). Top panel: curves are plotted for control fish and test-fish employing all fish sampled during five TBB trips. Mid panel: curves are plotted for test-fish per TBB trip. Bottom panel: curves are plotted for below (< 55 cm and above (≥ 55 cm) minimum landing size. Drawn lines indicate mean survival (percentage over time), with shaded areas indicating 95% confidence intervals. Dots indicate the end of the monitoring time for individual fish that were alive at the end of the experiments.

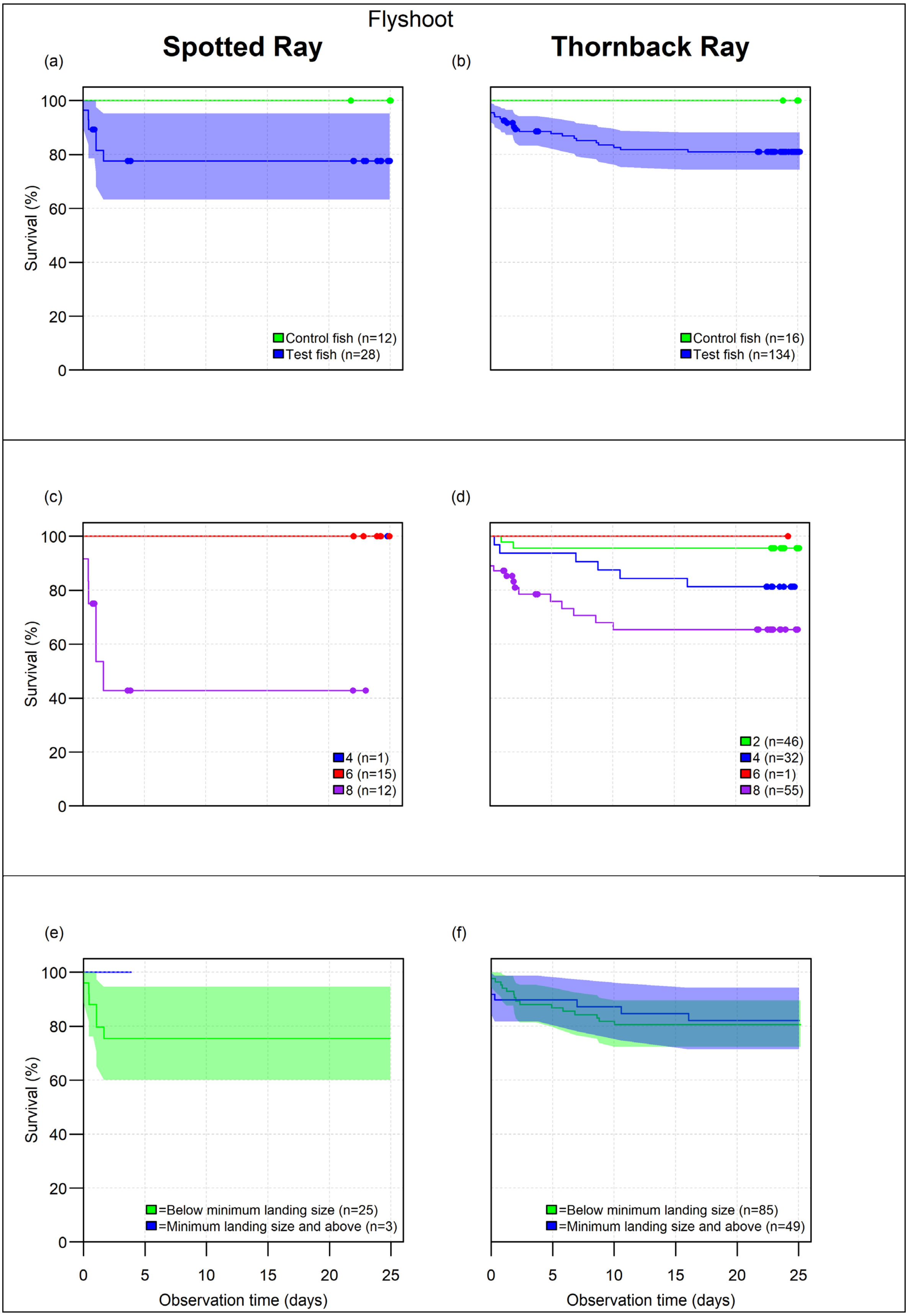

Figure 9: Kaplan-Meier survival curves for spotted (left) and thornback ray (right) discarded by flyshoot fisheries (SSC). Top panel: curves are plotted for control fish and test-fish employing all fish sampled during four SSC trips. Mid panel: curves are plotted for test-fish per SSC trip. Bottom panel: curves are plotted for below (< 55 cm and above (≥ 55 cm) minimum landing size. Drawn lines indicate mean survival percentage over time, with shaded areas indicating 95% confidence intervals. Dots indicate the end of the monitoring time for individual fish that were alive at the end of the experiments.

4.3.3 Effect of métier on distribution over vitality classes

The condition of all sampled rays was expressed by vitality classes A to D, with class A being the rays in the best condition and D in the worst condition. The frequency distributions for these vitality classes by species and métier (Figure 10) show a higher proportion of rays with a vitality score of A and B for flyshoot fisheries than for beam trawl fisheries. This difference in distribution across vitality classes is significant for both thornback ray ($p = 0.003$) and spotted ray ($p = 0.003$) using a Wilcoxon Rank Sum Test. This indicates that on average both thornback and spotted rays caught by flyshoot fisheries were in better condition than rays caught by beam trawl fisheries. The better condition of the rays is reflected by significantly higher discards survival probability estimates for both species caught by flyshoot fisheries (Table 7).

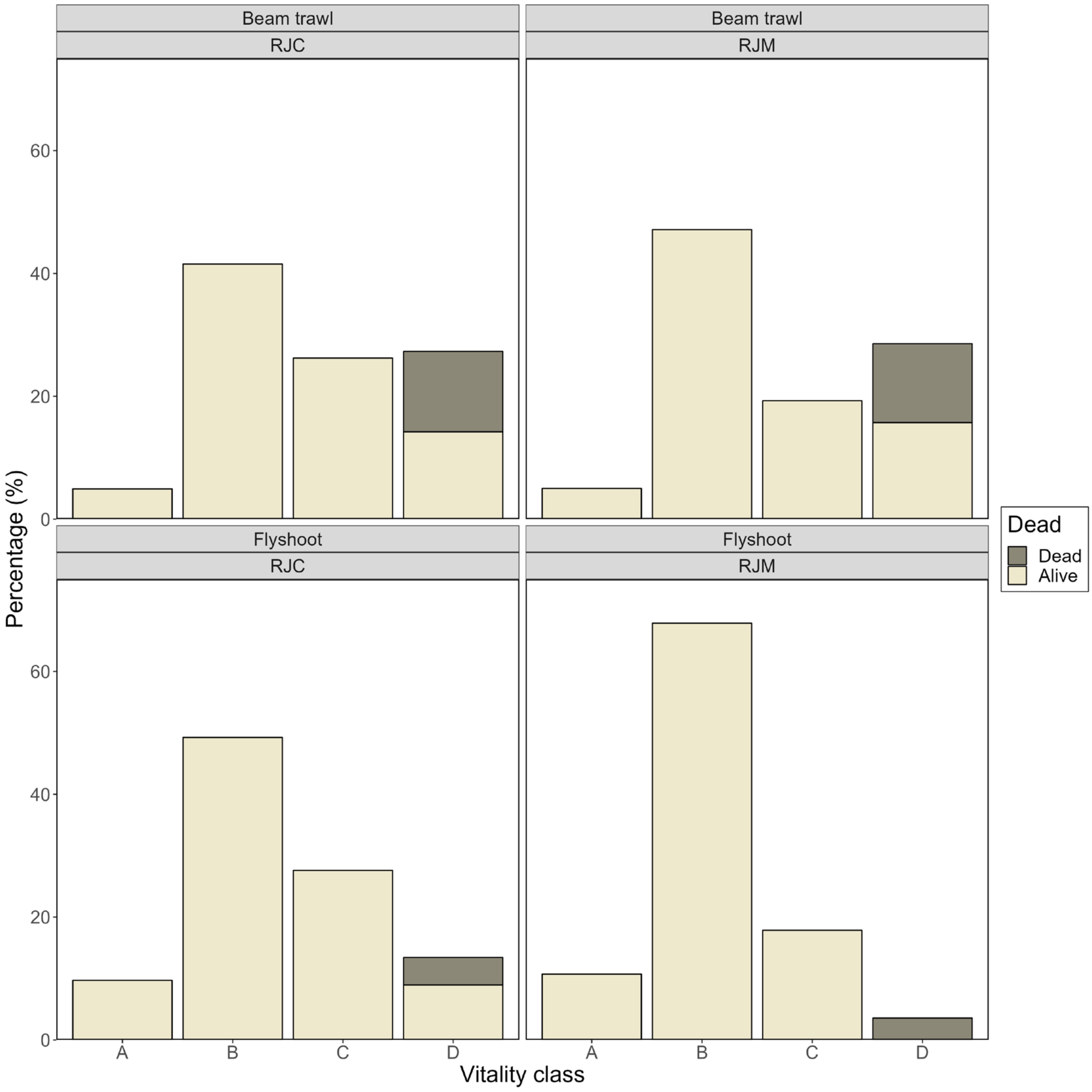

Figure 10: Relative distribution of vitality classes (A= good, D= poor) for rays sampled for discards survival measurements from beam trawling and flyshoot fisheries. RJC = thornback ray and RJM = spotted ray. The legend refers to the condition of rays at the moment of sampling.

4.3.4 Effect of vitality class on survival probability

The condition in which rays were landed on deck, expressed by vitality classes A to D, had a significant effect on discards survival probability (Figure 11, Table 9). For all species-métier combinations survival probability declined with deteriorating condition; in all cases survival probability was highest for vitality class A and lowest for vitality class D (Table 9). The effect of vitality class on survival probability is consistent across all métiers and species (Annex 3, although for spotted rays in flyshoot fisheries, sample size was too small to see any differences in survival between classes B and C).

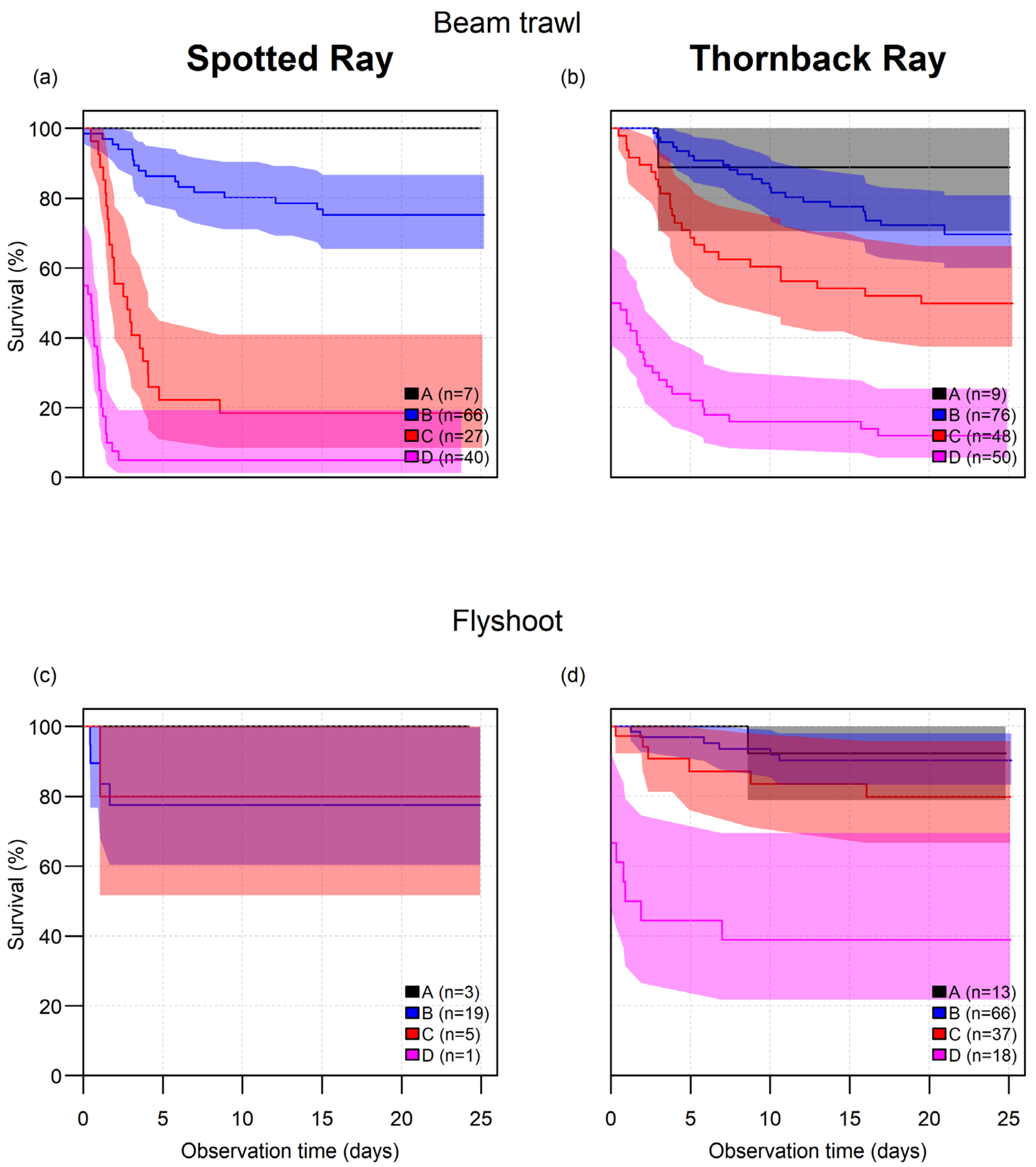

Figure 11: Kaplan-Meier survival curves for test-fish of vitality classes A to D for spotted (left) and thornback ray (right) discarded by beam trawl (top panel) flyshoot fisheries (bottom panel). Note that vitality class D includes fish that were dead at the start of the experiment. Drawn lines indicate mean survival percentage over time, with shaded areas indicating 95% confidence limits.

Table 9: Survival probabilities (%) and their 95% confidence intervals per vitality class of spotted and thornback rays discarded by beam trawl and flyshoot fisheries. Vitality classes in superscript show significant results ($p < 0.05$) for the pairwise post-hoc tests (using the *pairwise_survdiff* function from the *survival* package) between that vitality class and the other classes.

Species	Gear	A	B	C	D	Sign.? (p-value)
Spotted ray	TBB	100% (100-100)^{C,D}	75.3% (65.5-86.6)^{C,D}	18.5% (8.4-40.9)^{A,B,D}	5% (1.3-19.3)^{A,B,C}	Yes (p << 0.001)
	SSC	100% (100-100)	77.5% (60.3-99.7)^{D}	80.0% (51.6-100)	0% (0-0)^{B}	Yes (p << 0.001)
Thornback ray	TBB	88.9% (70.6-100)^{D}	69.6% (60.0-80.8)^{C,D}	49.8% (37.5-66.2)^{B,D}	12.0% (5.7-25.4)^{A,B,C}	Yes (p << 0.001)
	SSC	92.3% (78.9-100)^{D}	90.3% (83.3-98)^{D}	79.9% (66.6-95.8)^{D}	38.9% (21.8-69.4)^{A,B,C}	Yes (p << 0.001)

4.3.5 Predictors of mortality

Generalized Linear Mixed-Effect Models (GLMMs) were used to study which variables best explain the mortality observed for the two ray species sampled from catches of beam trawl and flyshoot fisheries. Out of models with all combinations of the variables gear, length, haul duration, processing time, sea surface temperature, depth, wind speed, species and the interaction effect between gear and haul duration, the model that best explained the data contained the variables sea surface temperature, gear, processing time, wind speed and the interaction effect between gear and processing time. This model had an AIC value of 605.8. Figure 12 gives the probability distributions with 95% CI's for the effects of these variables on mortality. Figure 12a shows that the probability of mortality increases with sea surface temperature ($p = 0.013$). Figure 12b shows the relation between mortality and fishing gear, which shows that mortality is higher in beam trawl fisheries than in flyshoot fisheries ($p < 0.001$). The relation between mortality and processing time was also included in the model, but was not significant ($p = 0.097$) (Figure 12c). Figure 12d shows the effect of wind speed on mortality, which was also not significant ($p = 0.070$).

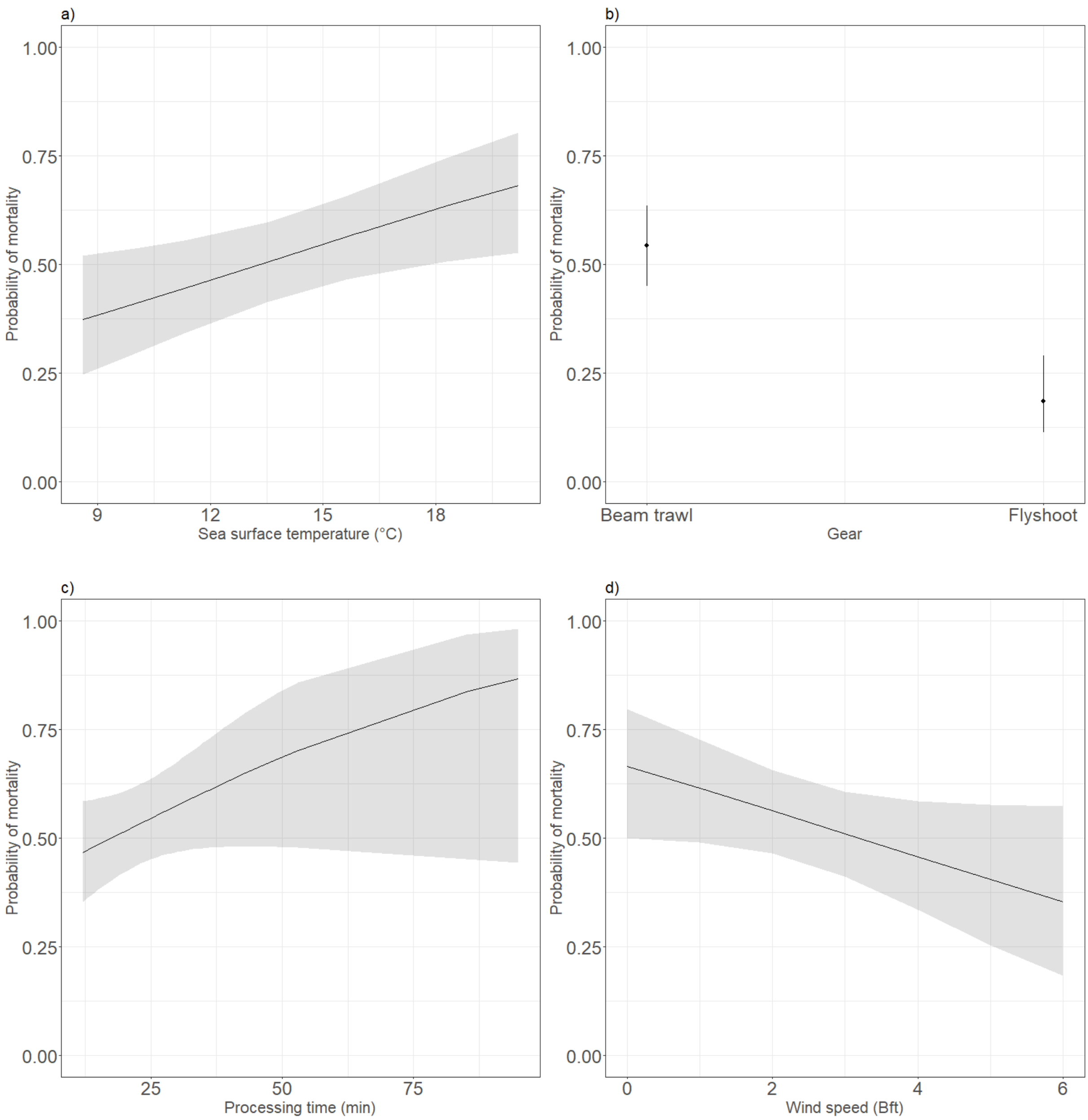

Figure 12: Predicted probabilities of mortality for the variables of the GLM with the lowest AIC value. Variables selected in the model were a) sea surface temperature, b) gear, c) processing time and d) wind speed. The graphs represent the probability of mortality at each value of the fixed effect with the other variables set to the mean value (or mode for non-numeric variables).

4.4 Discussion

The main objective of this study was to measure survival probabilities of rays discarded by Dutch demersal fisheries. Because highest ray catches are realized by beam trawl and flyshoot fisheries and concern thornback and spotted rays, these two species and métiers were selected for survival probability measurements. We conducted five trips with a beam trawler during which 184 thornback and 140 spotted rays were sampled and four trips with a flyshooter during which 134 thornback and 28 spotted rays were sampled. All mortality among sampled rays was considered to be fisheries induced since control rays showed 100% survival in all trips.

Fishing always involves some degree of internal or external injury of fish resulting from interactions between fish and fishing gear (Davis, 2002). Fish caught and discarded by commercial fisheries are exposed to stressors such as hypoxia, injury, exhaustion, barotrauma and predation during capture, handling, and release (Davis, 2002; Cook et al., 2019) and failure to recover from these fisheries induced stressors results in mortality (Cook et al., 2019). Because the severity of as well as the resistance to these stressor varies, it is not surprising that large variation in observed discards survival exists between species, métiers and sea conditions (Benoît et al., 2010; Morfin et al., 2017). To account for this variation and to determine representative overall discards survival probability estimates per species, we measured discards survival under variable conditions by spreading out the research trips over the year and combining the observations per trip into a single overall estimate per species. We indeed observed considerable variation in survival among trips, which could be attributed to water temperature, catch processing time, métier and wind speed.

We found that probability of mortality of discarded rays increased with temperature. In other words: discards survival was higher in winter when water temperatures were lower. This temperature effect may be caused by less severe hypoxia at lower temperatures. Hypoxia or oxygen deficiency in tissues generally occurs during air exposure as a result of collapsed gill lamellae which drastically reduces the fish' gas exchange capacity (Davis, 2002). Metabolic rates and oxygen demand increase with increasing temperature, while at the same time oxygen availability in the water is lower due to the decreasing water solubility of oxygen with increasing temperature. Both the impact of hypoxia and its incidence can therefore be expected to increase with increasing temperature. Next to temperature, characteristics of the fisheries such as haul duration, towing speed and total catch mass can affect the severity, incidence and duration of hypoxia. As survival probability declines with increased duration of hypoxic conditions, it is not surprising we found some evidence for lower survival probability with increasing catch processing time, i.e. increasing air exposure time. It then seems quite likely that hypoxia was an important stressor leading to mortality among rays in the catches. The decreased survival probability with increasing catch processing time may also be related to larger catches which take more time to process on board. Larger catches lead to denser crowding which exacerbates bruising, crushing and constriction injuries as fish are pushed against the cod-end mesh, other biota and debris (Veldhuizen et al., 2018). Unfortunately we have no reliable data on catch sizes to explore the effect of catch size on survival probabilities.

The effect of métier or gear, with a lower discards survival probability for beam trawl compared to flyshoot fisheries, can probably be attributed to differences in severity of stressors related to differences in fishing and catch processing procedures. The shorter time fish are retained in the cod-end (maximum 20 minutes instead of up to 120 min) and lower amounts of benthic organisms and debris in the catches in flyshoot fisheries, are probably key differences resulting in lower mechanical impact compared to beam trawling. The lower impact was reflected by a significantly better condition and lower direct mortality among rays sampled from the flyshoot fisheries. It should be noted that within métiers variation in discards survival may exist between individual vessels due to differences in fishing and catch processing procedures. We deliberately chose to conduct the research with a single vessel per métier for practical reasons and because an experimental design that would adequately account for vessel effects was not feasible within the available time and budget. Note that unless an experiment consists of a large number of trips, it will always be very difficult to disentangle vessel effects from effects of inevitably varying sea conditions between consecutive trips with different vessels. In case of beam trawl and flyshoot fisheries, differences in fishing and catch processing procedures are probably much larger between métiers than among vessels of the same métier, i.e. within métiers. Therefore we attribute the difference in discards survival probabilities observed between beam trawl and flyshoot fisheries to a métier effect rather than a vessel effect. In the comparison between métiers, we thus consider the survival probability estimates representative for the métiers.

Métier or gear effects are especially relevant if we aim to extrapolate survival probabilities to other gears. Next to beam trawling and flyshooting, twin and quad rigged otter trawling are important métiers within Dutch demersal fisheries. In comparison to beam trawling, otter trawls employ lighter gears that are towed at lower speeds, which probably leads to lower mechanical impacts on fish. This may explain the higher discards survival for thornback, blonde and spotted rays found for otter trawling compared to beam trawling at comparable catch processing times (Bogaert et al., 2020). However, since catch processing time also be longer in otter trawling, depending on its nature, and longer processing negatively affects ray discards survival, it is certainly not obvious that ray discards survival is higher for all otter trawling compared to beam trawling.

We found some evidence for a negative effect of wind speed on mortality probability, which contrasts our predictions. Higher wind speeds result in higher waves which are likely to increase physical strain on fish in the trawl during fishing, hauling and catch processing and exacerbate the incidence and severity of injuries to the fish. We would therefore predict a positive effect of wind speed on mortality. In other words: we would predict higher survival when seas are calm. Correlation between high wind speed and other variables that increase mortality, such as low water temperature or gear, would provide logical explanation for this unpredicted observation. However, such correlations are not present in our data. Therefore we have currently no explanation for the possible negative effect of wind speed on mortality.

No effect of species was detected; discards survival probabilities were the same for thornback and spotted ray across métiers. This however may not mean that discards survival studies dedicated to other species, such as blonde ray, are not needed because previous discards survival studies showed clear differences among ray species discarded by beam trawl fisheries (Van Bogaert et al., 2020). The highest survival was observed for blonde ray. For thornback ray the survival probability of 56% reported by Van Bogaert et al. (2020) is just slightly higher than what we observed for this species. However, for spotted rays these authors report a much lower survival probability than we report here (27% vs. 45.5%). We have no explanation for these differences in species effects on survival probabilities, but it should be noted that the number of observations in the study by Van Bogaert et al. (2020) is rather low compared to the present study (21 vs. 182 for thornback and 25 vs. 140 for spotted ray).

The survival probability estimates for rays discarded by beam trawl fisheries observed in this study are higher (≥ 45%) than we previously measured for the flatfish species plaice (14%), sole (19%) and turbot (30%) in pulse trawl fisheries (Schram and Molenaar, 2018). It seems that rays are more resistant to the fisheries induced stressors than the flatfish species. The larger body size of rays does not seem to play a role as the lower end of the length distribution of the rays overlaps with the length of undersized flatfish while no length effect on survival was detected among the rays in this study.
In agreement with the absence of a length effect, survival probabilities for rays below (< 55 cm) and above current minimum landing sizes were equal. This means that 20 to 50% of market sized rays that are discarded because they are over-quota do not survive.

Assessment of fish condition and assigning a vitality class A to D to each individual ray resulted in significant differences in survival probabilities among test-fish grouped by vitality class across species and métiers. Without exception vitality classes A and D always yield the highest and lowest discards survival probabilities. Vitality class thus proved to be a fairly good predictor for survival. Also, it is clear that the condition in which the fish arrive on the sorting belt has a strong effect on their survival chances when discarded. The effect of vitality class on survival was most pronounced for rays caught by beam trawl fisheries. In flyshoot fisheries, where survival was higher, differences in survival between vitality classes A, B and C were less pronounced. It is not clear to what extent survival probabilities can be quantified using vitality class and the underlying reflex impairment and damage scores as we did not attempt such mathematical model prediction. Since survival probabilities per vitality class were not the same for flyshooting and beam trawling it seems that métier specific survival per vitality class are needed to quantify survival based on vitality classes. For the moment, assigning vitality classes mostly seems a useful tool for qualitative assessments of survival probabilities, e.g. to gain first insight in effects of gear modifications within a métier on survival probabilities.

There are only a few other studies on ray discards survival to which we can compare our results. The survival probability observed in this study for thornback rays discarded by tickler chain beam trawl fisheries (49.6%) is just slightly lower than the survival of 53% we previously observed for this species in pulse beam trawl fisheries (Schram and Molenaar, 2018). This lower survival was expected because of the higher towing speed of tickler chain beam trawls (6-7 kn.) and generally larger catch volumes compared to pulse beam trawls (~ 5 kn.). Higher towing speeds may lead to faster exhaustion, exacerbate collisions with the net, other fish and debris, lead to more dense crowding and increased compression of fish in the codend. The small difference in survival probability is in line with earlier observations that condition of rays caught by tickler chain and pulse beam trawl fisheries did not differ (Schram et al., 2018). The higher survival of thornback ray (56.9%) and lower survival of spotted ray (27.5%) observed by Van Bogaert et al. (2020) in chain-mat beam trawl fisheries is difficult to explain by a gear effect. The mechanical impact of beam trawls with chain mats on fish could be both higher and lower compared to tickler chain beam trawls: lower because of the lower towing speed and higher because of the heavier gear and the generally larger amounts of debris in its catches. Also, we would expect a gear effect to be consistent among species, similar to what we observed for beam trawl versus flyshoot fisheries, but this is not the case: thornback survival was higher while spotted ray survival was lower for chain-mat beam trawls. A short-term survival of 72% was observed for unspecified ray species sampled from catches of eurocutters with chain mat beam trawls (Depestele et al., 2014). Based on the sampling area it is likely that the ray species were at least partly thornback and spotted rays. It is highly likely that the higher survival compared to our findings can be attributed to the short monitoring period of 80h as our results clearly show that mortality may occur up to 15 days post capture. In other words: short term survival monitoring probably under estimates actual survival probabilities. The observations in this study for thornback and spotted rays are to the best of our knowledge the first observations for discard survival for any species discarded by flyshoot fisheries. Consequently there are no previous studies to which we can compare our results.

5 Conclusions and recommendations

In this study we established the following discards survival probabilities (95% CI):

- 45.5% (37.9-54.5) for spotted ray discarded by tickler chain beam trawl fisheries with 80 mm cod-end meshes;
- 49.6% (42.9-57.4) for thornback ray discarded by tickler chain beam trawl fisheries with 80 mm cod-end meshes;
- 77.6% (63.3-95.2) for spotted ray discarded by flyshoot fisheries with 80 mm cod-end meshes;
- 81.0% (74.4-88.2) for thornback ray discarded by flyshoot fisheries with 80 mm cod-end meshes.

Survival probability is higher for rays discarded by flyshoot fisheries compared to beam trawl fisheries. Survival probability of discarded rays decreases within increasing water temperature and probably catch processing time. Species and body length did not affect survival probability.

Survival probability was highest for rays that were landed on deck in good condition.
To further increase survival probability it is recommended to keep catch processing time as short as possible and to focus on gear modifications that reduce stressors inflicted upon fish during the catch and hauling process to increase the proportion of rays that is landed on deck in good condition.

Current results strictly apply to tickler chain beam trawling, flyshooting, thornback ray and spotted ray. Extrapolation of these results to other species and métiers is not obvious. Additional discards survival studies are needed in case insight in discards survival of other ray species or in other métiers is needed.

6 Acknowledgement

The following contributors were indispensable for our research into discards survival of rays:

- Owners, skippers and crews of all the participating fishing vessels for welcoming researchers with all their equipment on board and assisting them whenever needed;
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- Visserijinnovatie Centrum Zuidwest Nederland for transporting all equipment to the fishing vessels and for maintaining all equipment in proper condition.
- PO Urk and Nederlandse Vissersbond for acquisition of the participating vessels.

7 Quality Assurance

Wageningen Marine Research utilises an ISO 9001:2015 certified quality management system. The organisation has been certified since 27 February 2001. The certification was issued by DNV.

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Justification

Report C018/23
Project Number: 4311400041

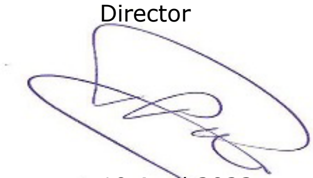
The scientific quality of this report has been peer reviewed by a colleague scientist and a member of the Management Team of Wageningen Marine Research

Approved: R. van Hal
Colleague scientist

Signature: 

Date: 19 April 2023

Approved: Dr.ir. T.P. Bult
Director

Signature: 

Date: 19 April 2023

Annex 1 Vessel and gear specifics

Vessel and gear specifics of the vessels participated in this project in either the exploratory trips or the survival trips are presented in Table 10 for the beam trawlers and the twin-rigged otter trawler and in Table 11 for the flyshooters.

Table 10: Vessel and gear specifics of beam trawlers (TBB) and twin-rigged otter trawler (OTB) used in exploratory trips and survival trips.

		Vessel 1	Vessel 2	Vessel 3	Vessel 4
Role in project	Type of trips	Exploratory	Exploratory	Exploratory	Survival
	Number of trips	1	2	1	5
Vessel	Gear	OTB	TBB	TBB	TBB
	Engine power (Kw)	340	1280	1470	1888
	Tonnage (GT)	335	348	418	494
	Length (m)	30	40.40	39.85	42
	Fishing speed (kn)	3.1	6.0	6.0-6.5	6.1
	Width (m)	n.a.	1	1	1
Beam (wing)	Length (m)	n.a.	12	12	12
	Total weight (kg)	n.a.	1200	1200	n.a.
	Length (m)	36	36	37	37
Ground rope	Diameter chain (mm)	18	24	24	24
	Length central rubber section ground rope (m)	12	6	7	7
	Total weight (kg)	n.a.	600	518	n.a.
	Tickler chains (n/gear)	n.a.	8	6	8
Chains	Net ticklers (n/gear)	n.a.	12	14	14
	Total weight (ton)	n.a.	-	-	2x 2.3
	Mesh size cod-end (mm)	115	80	80	80
Trawl	Total length (m)	n.a.	n.a.	n.a.	40
	Door spread (m)	225	n.a.	n.a.	n.a.
	Height (m)	1.0	0.4	n.a.	0.6

Table 11: Vessel and gear specifics of flyshooters (SSC) used in exploratory trips and survival trips.

Vessel		Vessel 5	Vessel 6
Role in project	Type of trips	Exploratory	Survival
	Number of trips	1	4
Vessel	Gear	SSC	SSC
	Engine power (Kw)	680	680
	Tonnage (GT)	310	340
	Length (m)	34	31
	Height (m)	10	10
Trawl	Cod end mesh size (mm)	80	80
	Length (m)	2x 2900	2x 2900
Flyshoot rope	Diameter (mm)	50	50
	Weight (kg/m)	1.85	1.85
	Length (m) incl. chain & sweeps	146.7	146.7
Ground rope	Disc diameter (mm)	240	280
	North sea	Yes	Yes
Escape panel	Eastern Channel	Yes	No
	Mesh size (mm)	110	110

Annex 2 Recovery

The distributions over vitality classes as observed directly after capture and 21-25 days later at the end of the survival monitoring period clearly show a shift over time towards better condition (Figure 13). This shows that surviving rays not only survive but also recover from damages sustained during the capture process. Overall, rays in better condition (vitality class A and B) at the start tend to recover the best and suffer the lowest mortality. Rays in poorer condition (vitality class C and D) at the start show less recovery and suffer higher mortality. In general, most rays either recover to better vitality scores (A) or they die. A small portion of rays end with vitality score D, which implies that the condition of these rays was still deteriorating at the end of the study period and that these rays probably would have died in case they were monitored for a longer period. This then implies that we may have underestimated survival probabilities in some case as a result of a too short monitoring period. However, since this is only a small portion of rays, the monitoring period was adequate.

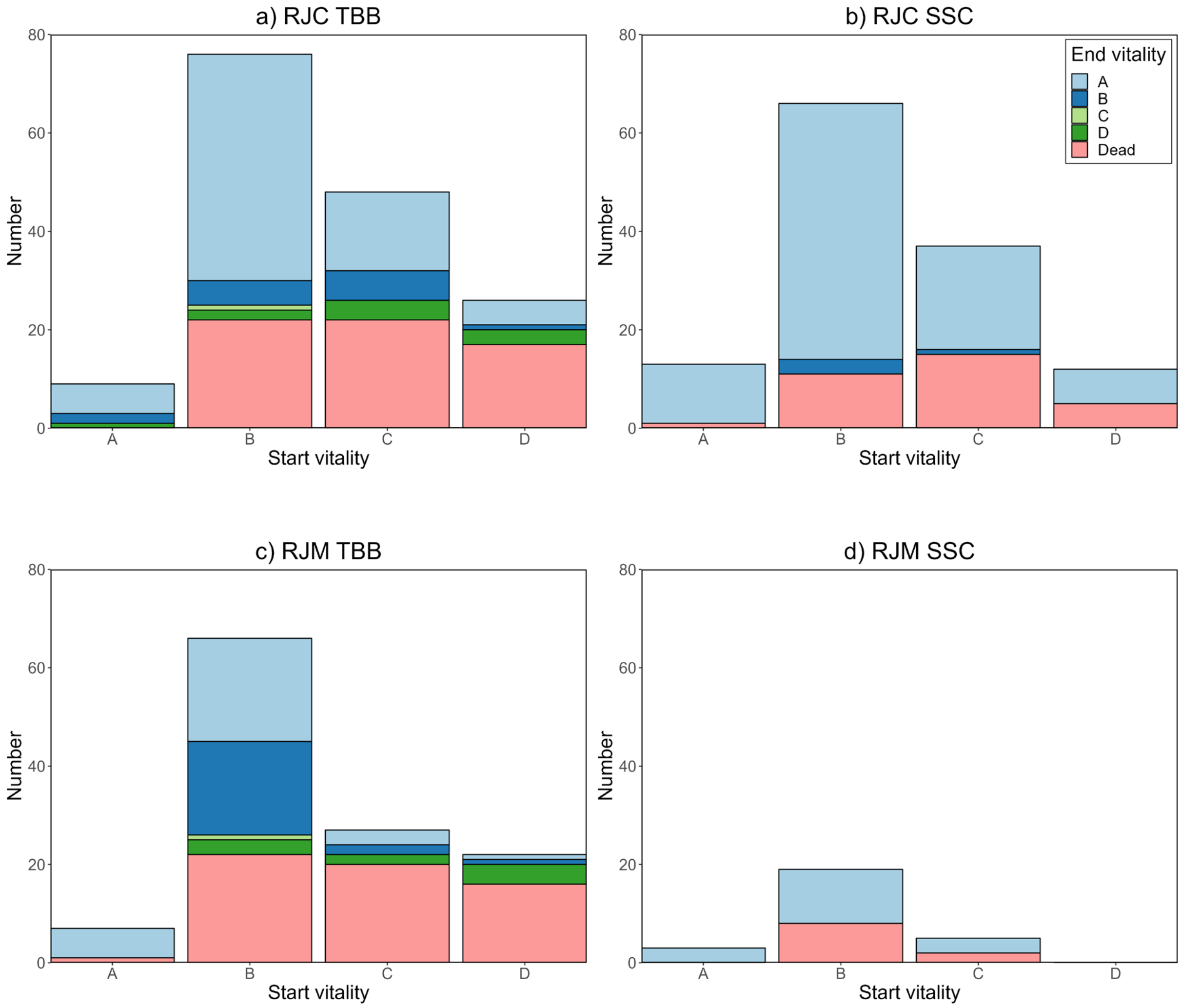


Figure 13: Distribution of rays in vitality classes at the beginning and end of the study period for a) thornback ray in beam trawl fisheries, b) thornback ray in flyshoot fisheries, c) spotted ray in beam trawl fisheries and d) spotted ray in flyshoot fisheries.

Annex 3 Reflex impairments and damage scores as predictors of mortality

To assess the effectiveness of the reflexes and damages scored at the start of the experiment to express fish condition by vitality scores (Figure 14), the percentage of rays scoring ‘1’ (reflex impaired, damage present) was calculated for rays that survived and rays that died during the monitoring period. If these percentages are similar to the distribution of alive and dead rays in the population, this means the reflex or damage is a weak predictor for mortality. Figure 14e shows that the spiracles, tail and eye reflex and visible intestines and wounds are the best predictors of mortality. Figure 14a-d gives the distributions for each combination of species and gear, and shows similar results. These are also the reflexes and impairments with the lowest incidence.

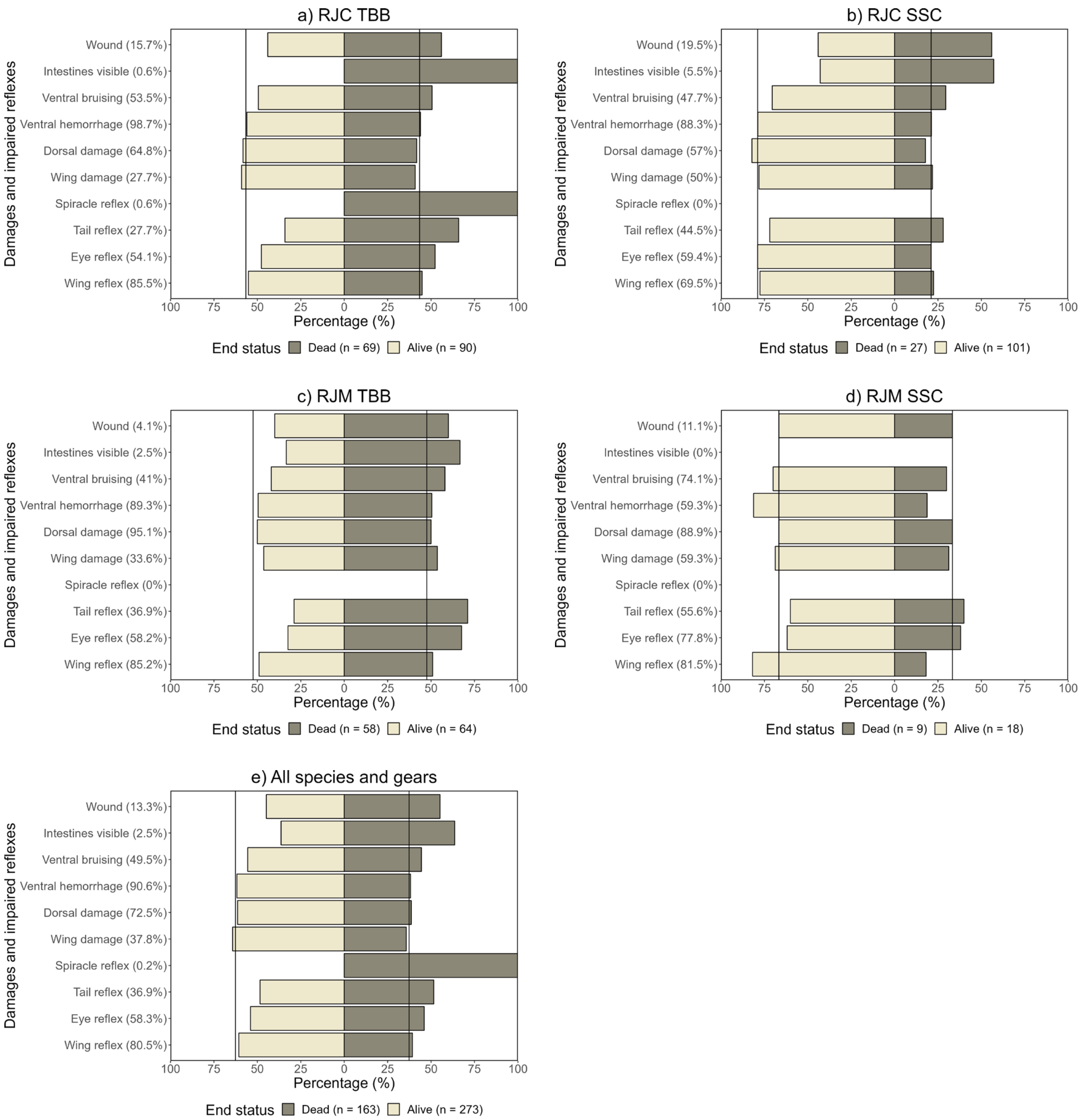


Figure 14: Percentages of rays scoring ‘1’ (damage or impaired reflex) for rays that survived and rays that died. Vertical lines display the distribution of rays that survived or died in the population. For each damage or impaired reflex, the percentage of rays that scored 1 of the total population is given. Damages and reflexes where the distribution of dead and alive rays deviates from the distribution of dead and alive rays in the population signify a good predictor of mortality. Rays that were dead upon sampling were not considered.

Annex 4 Vitality class as a predictor of mortality

Generalized Linear Mixed-Effect Models (GLMMs) were computed to determine whether vitality class is a suitable predictor of mortality, or whether vitality class cannot be applied across species, fish lengths, and gears to predict mortality. To do this, models were computed explaining mortality with all combinations of the variables vitality class, gear, species, length and the interaction effects between these as explaining variables. The minimum number of included (interaction) effects was one and the maximum six. The numerical variables (length) were normalized to increase the performance of the models. The models with the best fit were identified by comparing AIC values. Using the *plot_model* function in the *plot_model* package, we plotted the predicted probabilities of a fish not surviving until the end of the experiment as a function of the selected fixed effects.

Models with all combinations of the explaining variables vitality class, gear, species, length and the interaction effects between these were computed. The model that best explained the data (i.e. had the lowest AIC) contained the variables vitality class, gear, species and the interaction between gear and species. The probability of mortality differs for vitality classes A-D, with A, C and D being significantly different from each other (A: $p = 0.008$, C: $p < 0.001$, D: $p < 0.001$) and B not differing significantly from A (B: $p = 0.11$) (Figure 15). The effect of gear *in this model* is not significant ($p = 0.708$). This is also the case for species ($p = 0.185$), and the interaction effect between gear and species ($p = 0.057$).These results imply that vitality class is a suitable qualitative predictor of mortality that can be consistently applied for both species and gears studied, because the variation in mortality is captured by vitality class rather than species, gear and length.

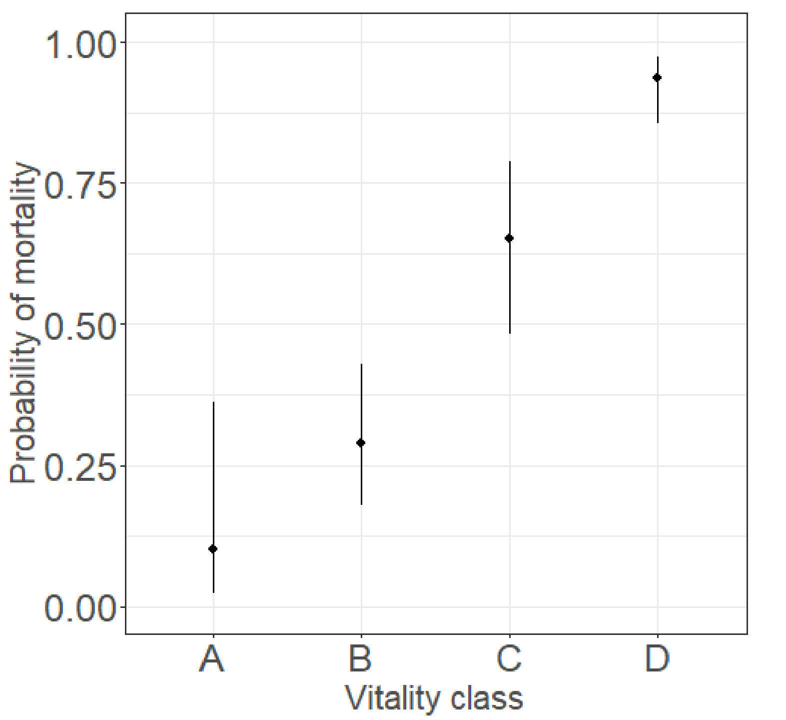


Figure 15. Predicted probabilities of mortality for the GLM with the lowest AIC value. Variables selected in the model were vitality class, gear, species and the interaction effect between gear and species. Only vitality class was a significant predictor of mortality in this model. The other, non-significant effects are not shown. The graph represents the probability of mortality at each value of the fixed effect with the other variables set to the mean value (or mode for non-numeric variables).

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