Building with Nature

EcoShape

Habitat suitability rules for the shallow coastal zone in The Netherlands

Project report

Project:	EDD 2 Tools and Valuation
Report title:	Habitat suitability rules for the shallow coastal zone in The Netherlands
Report number:	C064/12
Authors:	K.E. van de Wolfshaar S. Glorius M. van der Sluis
Project management:	K.E. van de Wolfshaar

IMARES is:

- een onafhankelijk, objectief en gezaghebbend instituut dat kennis levert die noodzakelijk is voor integrale duurzame bescherming, exploitatie en ruimtelijk gebruik van de zee en kustzones;
- een instituut dat de benodigde kennis levert voor een geïntegreerde duurzame bescherming, exploitatie en ruimtelijk gebruik van zee en kustzones;
- een belangrijke, proactieve speler in nationale en internationale mariene onderzoeksnetwerken (zoals ICES en EFARO).

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Contents

1. Context and project definition

Sand nourishment is an essential part of the long term flood defense strategy of the Dutch coast. A distinction can be made between beach nourishments and underwater nourishments. This report concerns underwater nourishments. Nourishments have ecological consequences that differ between species living in the shallow coastal zone (between 0.5 and 8 m water depth). In addition, different nourishment scenarios, such as mega-suppletions or shoreface suppletions, will have different ecological impacts in space and time and depending on species present. The trade-off of the ecological consequences for the different species for the different nourishment scenarios, positive - negative - neutral, is difficult .
An additional complication is that the ecosystem in this shallow zone is not well studied because it is too shallow to use a ship, and too deep to walk. Hence, knowledge on abiotic and biotic conditions in which species live is scarce. However, some studies were done in the shallow zone and knowledge on the use of the shallow zone by fish is recently developed in the projects Zandmotor and Building with Nature HK3.8 Smart Nourishments.

In general, habitat suitability models are a tool that aid understanding of the habitat requirements of species and species groups. Moreover, these models allow for extrapolation in space and time to predict the suitability in other areas or to predict changes in suitability due to management measures. At the core of these models are functions of habitat suitability and (a-)biotic variables (Figure 1), which are combined with spatially explicit input maps of these (a-) biotic variables. With a GIS application (R, PCRaster, ArcGIS, Erdas etc.) the functions and input maps yield output maps that provide spatial information on suitability. By comparing results of different input maps on the habitat suitability, the ecological effects of different nourishment scenarios can be assessed.

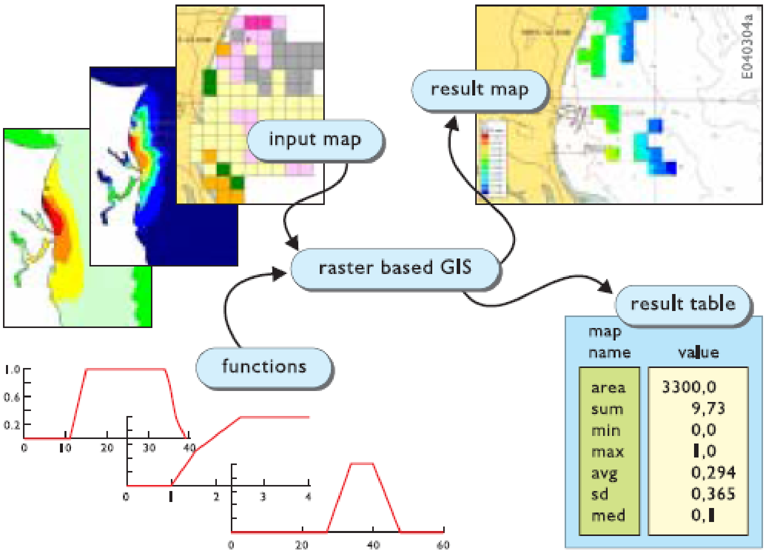

Figure 1. Scheme of a habitat suitability assessment (Graph from Deltares)

The purpose of this project was to make an inventory of existing knowledge on habitat suitability present within IMARES and collect this knowledge in a habitat suitability model. In addition, a list of all parameters needed to successfully use the habitat suitability rules is provided, which aids the use of the overall habitat suitability model. A workshop was organized to discuss the use of habitat suitability models in a forecasting context and the models present at IMARES. The report of this successful workshop can be found in Appendix A.

Alterations in physical properties of the habitat differ for different nourishment options based on the way of suppletion, the origin of the sand, time of the year, location, frequency etc. These alterations have to be predicted before the consequences of the scenario for the ecology can be determined. Habitat suitability models combined with physical modeling may then be used to study ecological effects of different nourishment scenarios for different species or groups of species, such as fish, mussels, birds and seals. These modelling tools can be used to advice on optimal strategies and designs of sand nourishments to improve ecosystem services in the shallow coastal zone.

2. Inventory

The inventory of habitat studies relevant for the shallow coastal zone, carried out within IMARES, yielded a total of 20 reports. Some studies only report on a single species (mostly mammals and birds) while others describe communities (e.g. benthos). While most studies were done on benthos, only one was done on fish (Figure 2). The difficulty of sampling and conducting field experiments, species mobility, and the importance of species based on Habitat Directive, Birds Directive and Marine Framework Directive all determine the current availability of habitat suitability studies for the different groups and species. Building with Nature project HK 3.8 (Teal & van Keeken 2011), dealing with habitat suitability of the shallow coastal zone for fish, shows the difficulty in sampling this turbid zone, such as keeping the vessel at the right location and speed and fish detecting the net and escaping.

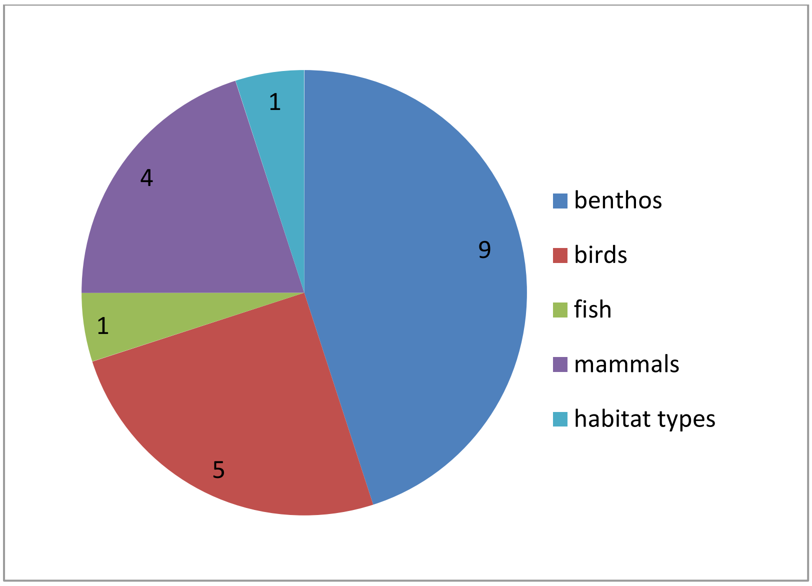

Figure 2. Number of IMARES studies per species group

Not all studies collected at IMARES were used in the habitat suitability model. A selection was made based on publication date (the most recent insights were used) and the usability of the modelling technique.
Different types of analyses are used with GLM (General Linearized Model) being the most common (Figure 3). Newer techniques, such as MaxEnt or Boosted Regression Trees, are not reported yet but are being used for suitability studies at the moment. The type of analysis influences the appropriateness of the models for further use. GAM (General Additive Model) for example can only be used for forecasting in combination with the original data that were used for the fit. This type of analysis can therefore, unfortunately, not be used in a 'stand-alone' habitat suitability model. GLM on the other hand can be used without the data as the coefficients can be extracted and saved for further use. Also the straightforward 'knowledge rules' can easily be used without the necessity of having the fitted data at hand.

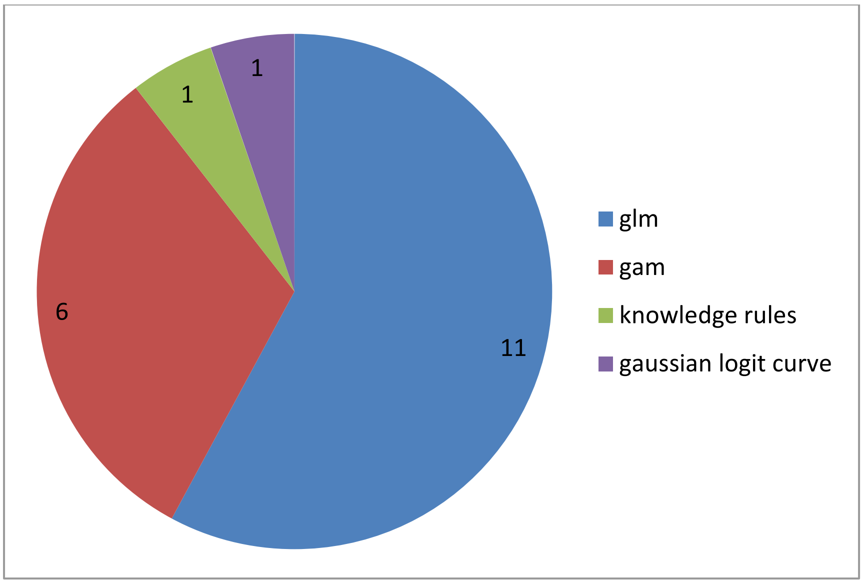

Figure 3. Type of analyses and there occurrence.

The 5 most commonly used abiotic variables are water depth, median grain size, maximum current, season and minimum salinity. Overall, 47 different variables were used in the 20 reports. This large number of variables indicates the possible difficulty of combining habitat suitability models and physical models for forecasting studies as not all necessary variables may be available for the wanted scenarios. It is therefore highly recommended that possible matches and/or mismatches in available variables, through physical modelling or field study, and needed variables, for suitability modelling, are identified a priori. This will aid the combined physical modelling – ecological modelling in order to assess the ecological consequences of different nourishment scenarios.

For fish suitability studies were done by Ingrid Tulp based on data from 'Maasvlakte' and the demersal fish survey, since no information was available with useable fits (Appendix B). This resulted suitability models for 6 species, sole, plaice, dab, European flounder, whiting and goby's. Suitability is GLM function of depth, salinity, Secchi depth, season and area. Figure 4 shows the average fish density in the Voordelta for the 6 species combined in spring.

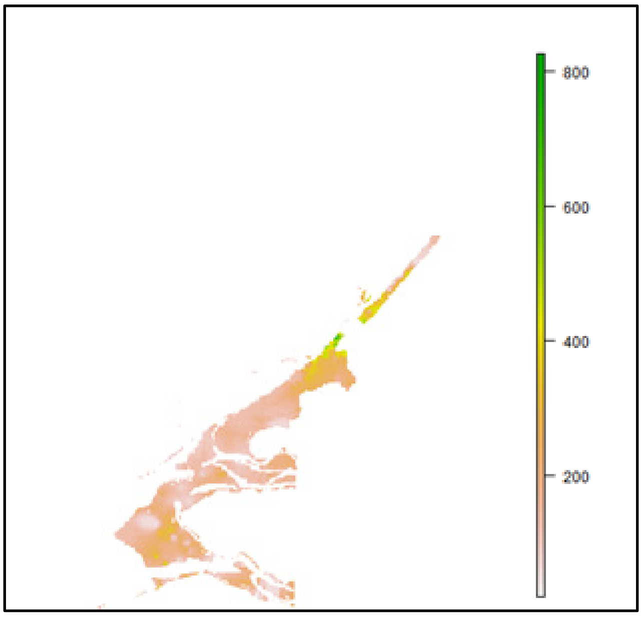

Figure 4. Average density (number/ha) predicted by the suitability models of 6 species combined (plaice, dab, sole, European flounder, whiting and goby's) valid for the Voordelta in spring.

For birds, Richard Witte (IMARES) developed suitability rules as the number of studies was limited to one on diving depth of Terns (Baptist & Leopold 2007) and a study on waders (Brinkman 2001) (Appendix C). Rules were developed for ducks (common eider, scaup, long-tailed duck, velvet scooter and black scooter) based on depth and for gulls (fulmar, guillemot, common gull and kittiwake) and common guillmot based on salinity.

In addition Richard Witte collected information on mammals, given that studies with useable functions, in terms of extracting model coefficients, could not be found (table 1) (Appendix D). Only for Benthos numerous studies were available but not all of them could be used (table 2) (Appendix E). When more reports were available describing the same study the latest version was used, which may occur when both a report and a peer-reviewed publication exists or when analysis updates were done.

Table 1: Overview of studies on mammals.

Author	Species	Area	Used	Model type	Comment
Richart Witte (Imares)	Harbor porpoise	North Sea	Yes	Knowledge rules	'expert judgement'
Leidraad aanwijzing artikel 20 Natuurbeschermingswet 1998 Waddengebied.	Harbour seal	North Sea	Yes	Knowledge rules	
Bouma et al. 2010	seals	Razende bol	No		
Aarts et al. 2008	Grey seal	East coast Scotland	No	GAM	
Brasseur et al 2005	Grey seal	North Sea	No	GAM	
Herr et al. 2009	Seal	German Bight	No	DSM	

Table 2: Overview of studies on benthos.

Author	Species	Area	Used	Model type	Output	Prediction
Brinkman & Hermes 2002 (mare 3.10a)	Bathyporeia elegans (amphipode)	NZK, Wad	Yes	GLM	biomass (+ density)	significant, but predictability?
Brinkman & Hermes 2002 (mare 3.10a)	Capitella capitata	NZK, Wad	Yes	GLM	biomass (+ density)	significant, but predictability?
Brinkman & Hermes 2002 (mare 3.10a)	Ensis arcuatus var. directus	NZK, Wad	Yes	GLM	biomass (+ density)	significant, but predictability?
Brinkman & Hermes 2002 (mare 3.10a)	Nephtys cirrosa	NZK, Wad	Yes	GLM	biomass (+ density)	significant, but predictability?
Brinkman & Hermes 2002 (mare 3.10a)	Spisula subtruncata	NZK, Wad	Yes	GLM	biomass (+ density)	significant, but predictability?
Brinkman & Hermes 2002 (mare 3.10a)	Macoma balthica	NZK, Wad	yes	GLM	biomass (+ density)	significant, but predictability?
Brinkman & Hermes 2002 (mare 3.10a)	Nephtys hombergii	NZK, Wad	Yes	GLM	biomass (+ density)	significant, but predictability?
Demesel et al 2011	Abra alba community	NZK	No	GLM/GAM/BRT	Probability present + number	GLM low pred., GAM/BRT higher
Demesel et al 2011	Donax vittatus	NZK	No	GLM/GAM/BRT	Probability present + number	GLM low pred., GAM higher.
Demesel et al 2011	Ensis sp.	NZK	No	GLM/GAM/BRT	Probability present + number	GLM low pred., GAM higher.
Demesel et al 2011	Macoma balthica	NZK	No	GLM/GAM/BRT	Probability present + number	GLM low pred., GAM higher.
Demesel et al 2011	Bivalve community	NZK	No	GLM/GAM/BRT	Probability present + number	GLM low pred., GAM higher.
Demesel et al 2011	Spisula solida community	NZK	No	GLM/GAM/BRT	Probability present + number	GLM low pred., GAM higher.
Demesel et al 2011	Spisula subtruncata	NZK	No	GLM/GAM/BRT	Probability present + number	GLM low pred., GAM higher.
Demesel et al 2011	Tellina fabula	NZK	No	GLM/GAM/BRT	Probability present + number	GLM low pred., GAM higher.
Demesel et al 2011	Macoma balthica community	NZK	No	GLM/GAM/BRT	Probability present + number	GLM low pred., GAM higher.
Welleman 2001	Crangon crangon	NZK	No	GLM	catch	??
Kater et al EVA 2 2004-2006	Cerastoderma edule	Oosterschelde, Wad	Yes	Logistisch (GLM)	biomass or prob. >50 cockels/m2	37.3 and 69% resp.
Tulp et al 2006	Crangon crangon	Voordelta	Yes	GLM	density (n/ha)	59%

Brinkman & Bult 2002 EVA II	Metulis edulis	WAD	Yes	GLM	suitability seeddrop + seed succes prob.	High, see R2
Bult et al 2003	Macoma balthica (nonnetje	WAD_west	No	GLM	Prob. present + density	Low predictability
Bult et al 2003	mossel	WAD_west	No	GLM	Prob. present + density	Low predictability
Bult et al. 2003	Cerastoderma edule (kokkel)	WAD_west	No	GLM	Prob. present + density	Low predictability
Steenbergen & Meesters 2006	Cerastoderma edule (kokkel)	Westerschelde	Yes	GLM (GAM + regressiontree + quartile regresion)	Pres-abs. (+ density)	R2= 0.22 (North) & 0.38 (South)

One study was done on marine Natura2000 habitattypes, including H1110_A Permanent flooded sandbanks (intertidal), H1110_B Permanent flooded sandbanks (North Sea- coastal area), H1110_C Permanent flooded sandbanks (Doggersbank), H1130 Estuaries, H1140_A Mud and sand flats (intertidal), H1140_B Mud and sand flats (North Sea- coastal area), H1160 Large bays and H1170 Open sea reefs (Jak et al., 2010) (Appendix F).

3. Habitat suitability models

The studies that were selected for the habitat suitability model are listed in the tables and text above. In case of follow-up studies the report of the latest date was used. Also, not all studies could be incorporated due the methods used, as mentioned above.

The habitat suitability model was programmed in R with use of the 'spatial' and 'raster' packages. R was chosen as it is commonly used within IMARES and code is easy to share and adapt. The model codes are provided in Appendix B-F, one appendix for each group. Note that the models are based on the current studies present within IMARES and they should be updated when new studies become available. It may also be expanded with studies from, for example, Deltares and national or international publications.

Per group of species a script is given, which can be copied and run in R. All scripts are set up in the same manner, starting with general information on package used and using a heading per species that include the reference, input maps needed and the area under consideration. At the end of each species specific code, a code for checking the result and saving it is provided. An example of a resulting suitability map is given in Figure 6, providing suitable foraging areas in the shallow coastal zone for the Sandwich Tern (*Sterna sandvicensis*). The suitability is a function of water depth (Figure 5) and water clarity (Secchi depth), provided by Baptist & Leopold (2007).

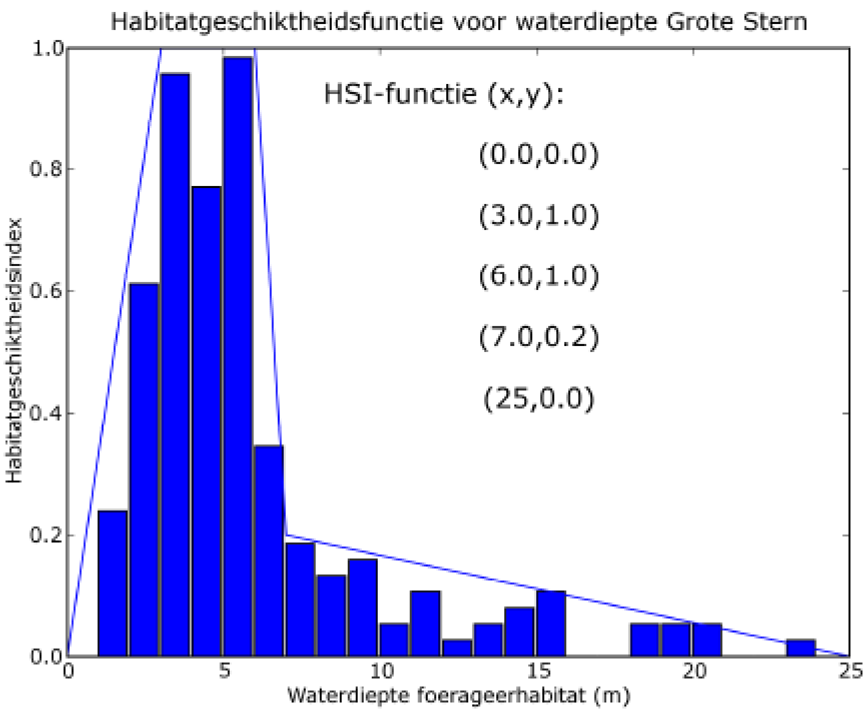

Figure 5. Habitat suitability as a function of depth (copy from Baptist & Leopold 2007)

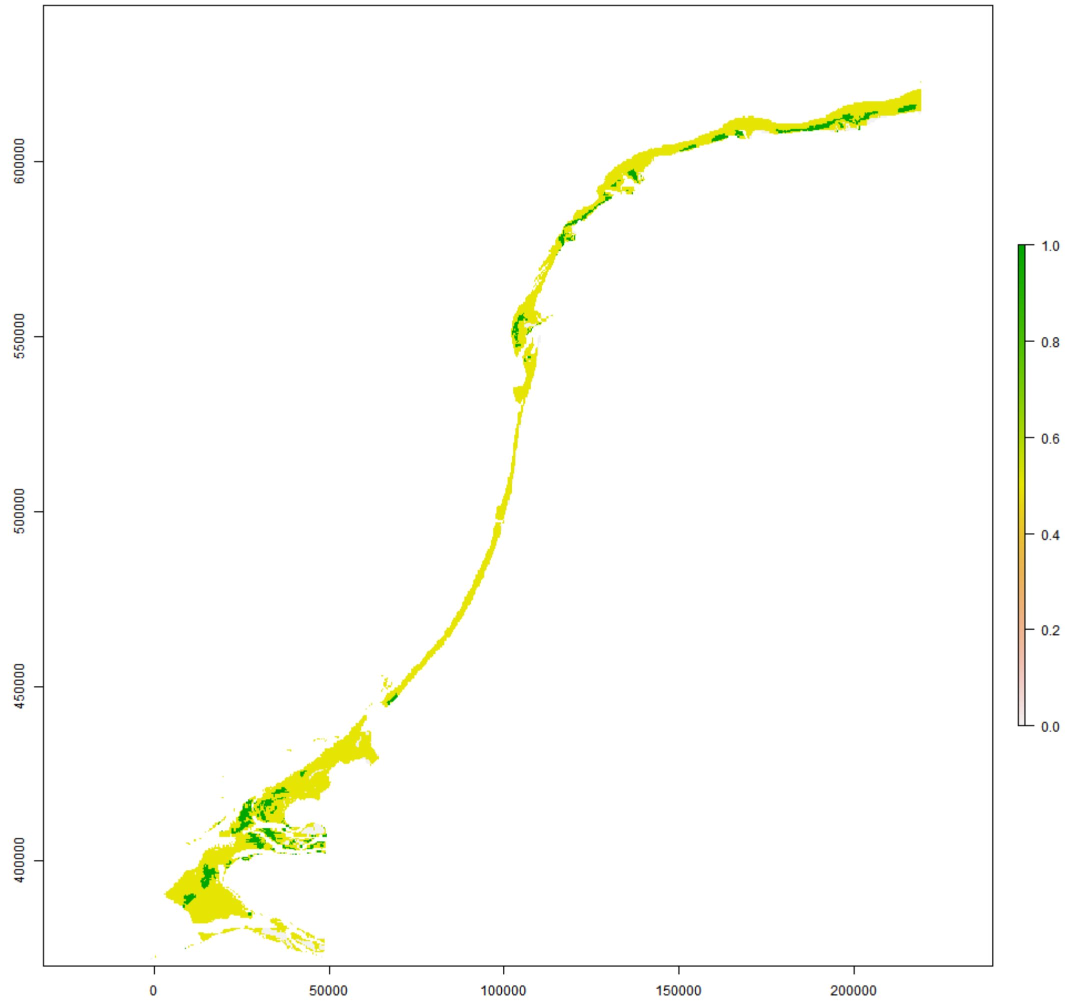

Figure 6. Foraging suitability for the Sandwich Tern, in the shallow coastal zone.

All scripts were tested for programming errors, but the functions were not validated. For validation and calibration information the reference provided for the function can be considered. Testing was done using maps provided by Deltares and some maps from IMARES from specific studies. Of all maps the shallow coastal zone was used for testing, i.e. water depths no more than 10 meters. The geographical ranges of the studies used are provided in the tables presented above and present in the model code.
After testing the scripts for the marine Natura2000 habitattypes it became clear that depth and/or emersion time should be added to the knowledge rules to discriminate between intertidal and non-intertidal areas as in the current study the knowledge rules for the two variants are identical. Spatially explicit use of the rules is also an option to select the intertidal or the non-intertidal zones and then use the rules to assess the suitability for the habitat type applicable.

4. General remarks

In general, knowledge gaps on habitat suitability especially exist for more mobile species such as fish and mammals. Studies on benthic organisms show that habitat suitability relationships can differ on small local scales, i.e. fits for the Western Scheldt do not apply for the Eastern Scheldt, nor Wadden Sea. Note that this holds for species that are relatively well studied. Suitability models are static, which means that colonisation time is not accounted for. Nor are population dynamics or interactions with other species considered. For example, the abiotic conditions may be highly suitable but with a predator or competitor present the predicted biomasses are unlikely to be achieved. Moreover, for abiotic conditions holds that mostly the ones measurable or ones thought to be of importance are included in suitability models and important conditions may be overlooked. Hence, care must be taken when using suitability models in a forecasting context.
Can they then not be used? Yes, they can, especially when used for an overall suitability in a coarse classification, rather than expecting a perfect estimate. Using habitat suitability models one must bare in mind that they are models, not facts, and that even the smallest of individuals is surprisingly complicated and its actions may not be captured by a statistical function. In addition, ‘suitability’ does not directly translate into ‘presence’. ‘Although my backyard is suitable for panda’s it is unlikely that they will be present there on their one account’ (quote from Martin Baptist).

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6. Justification

Report: C064/12
Projectnumber: 4306111066

The scienctific quality of this report has been peer reviewed by a collegue scientist and the head of the department of IMARES.

Approved: M. Baptist

Signature: 

Date: 24 May 2012

Approved: J. Schobben

Signature: 

Date: 24 May 2012

Appendix A: Workshop report

Verslag bijeenkomst 'Habitat suitability shallow coastal zone'.

Datum: 29-09-2011

Aanwezig:	Karen van de Wolfshaar (KvdW) Martin Baptist (MB) Bert Brinkman (BB) Sander Glorius (SG)	Cor Smit (CS) Johan Craeymeersch (JC) Marieken van der Sluis (MvdS) Sophie Brasseur (via skype) (SB)
Afwezig:	Hariette Holzhauer (Deltares)	

Agenda
1. inleiding
    1.1 doel van het habitat model
    1.2 resultaten inventarisatie

2. discussie
    2.1 hoe kunnen bestaande modellen gebruikt worden voor de kustzone
    2.2 kunnen we voor minder bestudeerde soorten kennisregels afgeleiden

Inleidende presentatie
KvdW geeft een inleidende presentatie met daarin het doel + het resultaat van de inventarisatie.

Doel project
Vaststellen van habitatgeschiktheidsregels voor de kustzone (tot 10 m. diep) voor de marine soorten (benthos, vis, zeezoogdieren en vogels) om zandsuppletie scenario's te kunnen beoordelen op ecologische impact, dan wel ecologisch toegevoegde waarde (creëren van kraamkamer functie bijvoorbeeld). Alleen kennis aanwezig binnen IMARES wordt meegenomen in het vaststellen van habitatmodellen/kennisregels.

Suppletie scenario's voor de langere termijn liggen niet per definitie vast, deze kunnen ook vanuit de ecologie ontwikkeld worden of in vanuit een combinatie ecologie-fysica-beleid. Ook is het mogelijk om vanuit ecologisch oogpunt aanpassingen in een suppletieontwerp aan te brengen. Habitatgeschiktheid wordt bij voorkeur niet alleen bepaald voor indicatorsoorten voor Natura 2000 en Flora en Faunawet, maar er wordt getracht de voor het ecosysteem belangrijke soorten/soortgroepen op te nemen. Voor het ontwikkelen van kennis, calibratie en validatie is beschikbaarheid van data een vereiste.

Resultaten inventarisatie
Uit een eerste inventarisatie (op dit moment bestaande uit 17 studies) blijkt dat er weinig habitat geschiktheidsstudies bestaan binnen IMARES voor vogels (2 studies) en vis (1 studie). Voor benthos bestaan de meeste modellen.

BB geeft aan dat er nog meer studies zijn waarbij is gekeken naar de habitat geschiktheid voor vogels → *KvdW stuurt herinneringsmail om deze op te sturen zodat ook deze studies kunnen worden meegenomen in het model.*

In de gedane studies zijn voornamelijk GLM en GAM modellen geconstrueerd. De nieuwste ontwikkeling in modellen is het gebruik van BRT, MARS en MaxEnt modellen, maar deze zijn nog niet bij Imares verschenen rapportages toegepast.

Er blijkt een negatieve relatie te bestaan tussen het aantal indicatiesoorten voor mariene diversiteit (bv omschreven in Meesters et al.,) en het aantal studies per groep (vogels, vissen, benthos en zeezoogdieren). Voor invertebraten zijn er meer habitatstudies voorhanden dan dat er indicatorsoorten zijn gedefinieerd, maar voor vogels zijn bijvoorbeeld meer indicatorsoorten gedefinieerd dan dat er soorten bestudeerd zijn.

In de 17 studies van de huidige inventarisatie zijn 47 variabelen geïdentificeerd. Het aantal variabelen is mede zo groot doordat mediaan, percentiel, gemiddelde of maximale waarde als verschillende variabelen opgenomen zijn omdat deze niet een-op-een te wisselen zijn. De top 5 veel voorkomende variabelen zijn: Waterdiepte, mediane korrelgrootte, max. stroomsnelheid, periode (seizoen) en min. saliniteit. Een probleem met de gerapporteerde variabelen is dat niet altijd duidelijk is omschreven welke kwantiteit er precies gebruikt is. Bijvoorbeeld, indien 'waterdiepte' is gebruikt, is dat dan een jaargemiddelde, een seizoen gemiddelde, of een waarde tov NAP, enz? Bij studies waar de kwantiteit van de variabele niet expliciet is gegeven moet contact worden gezocht met de auteurs om de gebruikte kwantiteit te achterhalen. Zeker bij studies die al een aantal jaren geleden zijn uitgevoerd kan deze informatie lastig zijn om te achterhalen.

Discussie

Databeschikbaarheid

In de huidige situatie is er zeer weinig data beschikbaar over aanwezigheid van zowel vis, benthos en vogels in de Nederlandse ondiepe kustzone in het algemeen, en voor vogels van de Hollandse kust in het bijzonder (CS, BB).

MB + JC hebben wellicht nog enige benthos data in ondiepe wateren. Echter, een analyse zou een nieuwe studie betekenen.

MB: data over juveniele vis is beperkt tot oude RIVO data (recent geanalyseerd door Lorna Teal) en zeer sporadisch uitgevoerde monitoring. Het veldwerk van het BwN project, dat afgelopen zomer is uitgevoerd naar het voorkomen van vis in de ondiepe kustzone, is gedaan, maar de analyse is nog in volle gang.

CS heeft wellicht nog data beschikbaar over aanwezigheid vogels in de Voordelta. MvdS kan wellicht nog aan vogel data komen verkregen bij de monitoring van windmolens. Mardik Leopold heeft hiervan ook een goed overzicht. MB geeft aan dat Bureau Waardenburg mogelijk ook nog beschikking heeft over aanwezigheid vogels. Deze gegevens zouden een mogelijkheid kunnen bieden om in een vervolgstudie voorkomen en abiotische relaties te bestuderen, afhankelijk van de kwaliteit van de gegevens.

Mogelijkheid vertalen modelresultaten naar een nieuw (kustzone) gebied

Bij extrapolatie van habitatmodel-regels naar andere gebieden in de Nederlandse kustzone kan er een fout optreden in de variabelen. Dit kan gebeuren als een variabele gebruikt is om een andere variabele te bepalen. B.v. waterdiepte welke bij de ene studie gebruikt is om droogvalduur te bepalen kan niet in alle gevallen 1 op 1 gebruikt worden in een andere situatie omdat bijvoorbeeld de getijamplitude daar anders is.

Daarnaast kan het zijn dat een gedeelte van de variatie door het niet beschikbaar zijn van variabelen verweven is in een andere wel beschikbare variabele. In deze variabelen zit dan feitelijk de variatie van een meerdere variabelen opgenomen. Vertalen van deze model resultaten naar een andere situatie wordt in dit geval bemoeilijkt omdat de relatie tussen beide variabelen in een andere situatie anders is.

Door gebied-specifieke eigenschappen zal het onmogelijk zijn generieke regels af te leiden voor de hele Nederlandse kust. Er zullen gebieden geïdentificeerd moeten worden waarvoor andere regels gelden. Het gebied kan in dit geval worden opgenomen als een variabele. Dit wordt aanbevolen (JC, BB) voor benthos waar functies voor Waddenzee, Oosterschelde en Westerschelde zijn gefit, die een slechte voorspeller zijn buiten het gebied van calibratie.
BB: Mits benthos data beschikbaar is en goed uitgezocht, is het uitvoeren van een nieuwe modelstudie specifiek voor de gehele kustzone van Nederland relatief snel gedaan. Een Nederland dekkende modelstudie kan eventueel uitgevoerd worden voor Ensis sp. Het beschikbaar maken en klaar zetten van de benodigde data is de kritieke stap en vergt veel investering (tijd). Een studie als deze zal dan ook in een vervolgstudie opgepakt moeten worden.

Anders dan de situatie waarvoor de huidige modellen opgezet zijn, is de kustzone dynamisch met een periodieke verstoring door zandsuppleties. Dit is wellicht de belangrijkste kennisleemte voor het opstellen van habitat modellen voor de kustzone op dit moment. Omdat er geen studies zijn gedaan die de hele periode voor, tijdens en erna een zandsuppletie omvatten, is alleen extrapolatie mogelijk wat een grote onzekerheid met zich meebrengt over de kennisregels in andere omstandigheden en dus ook omtrent het effect van deze andere omstandigheden. Ook ontbreekt het aan meetgegevens van tijdens en na zandsuppleties van bijvoorbeeld slibgehaltes en doorzicht (variabelen die voor een aantal soorten van belang zijn) en wellicht meer.

Het toepassen van meerdere modellen zou iets kunnen zeggen over de betrouwbaarheid. Wanneer verschillende modelresultaten hetzelfde resultaat laten zien wordt het betrouwbaardere bevonden dan wanneer modellen tegenstrijdige relatie opleveren.

Aanpak voor deze studie

De volgende aanpak is overeengekomen:

1. In eerste instantie gebruiken informatie die er nu ligt vanuit de verschillende studies (o.a. GLM vergelijkingen).
2. wanneer geen modellen voor handen zijn (vn voor vogels en zeezoogdieren) worden kennisregels gebaseerd op expert judgement ontwikkeld en gebruikt.
3. *Geïdentificeerde kennisleemtes worden aangeven zodat deze mogelijk opgenomen kunnen worden in projectvoorstellen in Building with Nature 2!*

KvdW: Door geïdentificeerde kennisleemtes en mogelijk ongeschiktheid om de bestaande kennis te vertalen naar een nieuwe omgeving (kustzone) maar toch iets te kunnen zeggen kan de volgende strategie gehanteerd worden, waarbij het habitatmodel uitsluitend laat zien wat zeker geen geschikte gebieden zijn en welke gebieden zijn die mogelijk potentieel geschikt zouden kunnen zijn.

Het habitatmodel zal alleen de mogelijke (of onmogelijke) potentie in kaart brengen, voorspellen van daadwerkelijke aanwezigheid is toekomstmuziek.

Modellen en kennisregels.

Uitsluitend lineaire relaties en GLM resultaten kunnen gebruikt worden omdat voor GAM, maar waarschijnlijk ook nieuwe technieken als MARS en BRT, de ruwe data beschikbaar nodig om de onderlinge relaties eerst uit te rekenen. De gefitte functie lijkt niet te kunnen worden geabstraheerd voor verder gebruik. BB merkt op dat GAM relaties mogelijk te extraheren zijn uit het R-script en dus alsnog gebruikt kunnen worden. KvdW merkt op dat dit gecheckt is bij o.a. Erik Meesters en Geert Aarts en tot op heden niet mogelijk blijkt… Wie het weet mag het zeggen!

SB zal kennis aanleveren om kennisregels op te stellen voor zeezoogdieren (zeehonden) als bekend is op welke variabelen de suppleties inspelen (bijvoorbeeld verstoring door vervoer en opspuiten van het zand).

Ingrid Tulp zal kennis aanleveren voor kennisregels voor vis. De analyse van de ‘strandbemonstering’, visbemonstering in de ondiepe kustzone vanaf het strand, is nog in volle gang en kan in een later stadium aan het model worden toegevoegd.

CS: de zwarte zee-eend is geen zichtjager, doorzicht is dus voor deze soort niet van belang. KvdW; dit soort informatie is belangrijk voor het opstellen van het uiteindelijke model!

Nuttige toekomstige ontwikkelingen

- Het wordt algemeen nuttig bevonden om een centrale database te hebben waaruit modellen gestructureerd kunnen worden. Wanneer zo’n database beschikbaar is kan makkelijker GAM/MARS/BRT modellen gerunt worden. Ook wanneer er nieuwe data beschikbaar komt is het makkelijk om modellen actueel te houden door ze steeds met de laatste data-updates te fitten. Initiatieven zoals OpenEarth van Deltares worden realistisch bevonden en ondersteund, al moet er nog wel een format worden gevonden voor de structuur van dataopslag van biologische gegevens waarvoor de in OpenEarth gebruikte NetCDF structuur niet de meest geschikte is.
- Het opzetten van een intranet, IMARES-wiki oid om de bestaande rapporten, kennis en wie-doet-wat beter te ontsluiten binnen IMARES
- Het fitten van een Ensis model voor de gehele Nederlandse kust door alle nu beschikbare data samen te brengen voor analyse
- Vogelgegevens verzamelen en analyseren

Appendix B: Fish suitability models - R code

```
#########################################################
# FISH Habitat suitability models based on raster maps
# IMARES
# date: december 2011
#########################################################
# comment: use phi unit for sediment
#          use depthplus; deeper= higher value

# These models are not validated
#########################################################
# Initial settings
#########################################################

# clear memory
rm(list=(ls()));

# load packages
library(raster) # for raster/grid algebra
library(sp)
library(lattice)
library(maptools)

# set home dir

direc  <-"N:/Projecten/Building with Nature - Habitat inventory/Model/input_maps_shallow/";
direc2  <-"N:/Projecten/Building with Nature - Habitat inventory/Model/results_fish/";
#########################################################
# Fish Species
#########################################################

#########################################################
# Voordelta PMR-Voordelta IMARES
####################
# Reference: Tulp 2011 IMARES UNPUBLISHED DATA
# Species: Pleuronectus platessa (schol)
# Model: density in n/ha (not validated)
# glm family used: Lineaire regressiemodellen zonder poission
## Area: voordelta (VD)
## Periode: voorjaar (VJ)

# Variable list:
  # Depth          = lokale waterdiepte (m)
  # Sed_med_phi    = mediane korrelgrootte sediment
  # Depth_may

# Create raster maps
Depth         <-raster(paste(direc,"depthplus.asc",sep=""));
Sed_med_phi   <-raster(paste(direc,"Sed_med_phi.asc",sep=""));


# Suitability function
Pleuronectus_suit_VD_VJ<-overlay(Depth, Sed_med_phi,
       fun=function(Depth, Sed_med_phi)
       10^(0.34815+0.83208+0.05721*Depth-0.09659*Depth+0.45412*Sed_med_phi));

#check result
plot(Pleuronectus_suit_VD_VJ)
summary(Pleuronectus_suit_VD_VJ)

# save result as asc file
  tt<- writeRaster(Pleuronectus_suit_VD_VJ, filename=
(paste(direc2,"Pleuronectus_suit_VD_VJ.asc",sep="")),format="ascii", overwrite = TRUE)

# save result as figure (for report)
  graphics.off();
  filen <- paste(direc2,"Pleuronectus_suit_VD_VJ.png",sep="")
```

```
  png(filen, width=1000, height=1000);
  plot(Pleuronectus_suit_VD_VJ)
  dev.off();

###
# Periode:  najaar  (NJ)

# Variable list:
  # Depth          = lokale waterdiepte (m)
  # Sed_med_phi    = mediane korrelgrootte sediment (phi)

# Create raster maps
Depth         <-raster(paste(direc,"depthplus.asc",sep=""));
Sed_med_phi   <-raster(paste(direc,"Sed_med_phi.asc",sep=""));

# Suitability function
Pleuronectus_suit_VD_NJ<-overlay(Depth, Sed_med_phi,
        fun=function(Depth, Sed_med_phi)
        10^(0.34815+0.05731*Depth+0.45412*Sed_med_phi));

#check result
 summary(Pleuronectus_suit_VD_NJ)
 plot(Pleuronectus_suit_VD_NJ)
# save result as asc file
  tt<- writeRaster(Pleuronectus_suit_VD_NJ, filename=
(paste(direc2,"Pleuronectus_suit_VD_NJ.asc",sep="")),format="ascii", overwrite = TRUE)
# save result as figure (for report)
  graphics.off();
  filen <- paste(direc2,"Pleuronectus_suit_VD_NJ.png",sep="")
  png(filen, width=1000, height=1000);
  plot(Pleuronectus_suit_VD_NJ)
  dev.off();

##########
# Reference: Tulp 2011 IMARES UNPUBLISHED DATA
# Species: Solea solea (tong)
# Model: density in n/ha (not validated)
# glm family used: Lineaire regressiemodellen zonder poission
## Area: Voordelta (VD)
## Periode: voorjaar  (VJ)

# Variable list:
  # Depth        = lokale waterdiepte (m)
  # Secci_m       = doorzicht (m) (zelf gemeten tijdens trek)
  # Sed_med_phi  = mediane korrelgrootte sediment (phi)

# Create raster maps
Depth       <-raster(paste(direc,"depthplus.asc",sep=""));
Secci_m     <-raster(paste(direc,"Secchi_avg.asc",sep=""));    # meter
Sed_med_phi <-raster(paste(direc,"Sed_med_phi.asc",sep=""));     # phi!!

# Suitability function
Solea_suit_VD_VJ<-overlay(Depth, Secci_m, Sed_med_phi,
        fun=function(Depth, Secci_m, Sed_med_phi)
        10^(0.02698+0.01345*Depth+0.05589*Depth-0.76264-
0.16034*Secci_m+0.52013*Sed_med_phi));
#check result
result <- Solea_suit_VD_VJ
 summary(result)
 plot(result)

 filename <-"Solea_suit_VD_VJ"
# save result as asc file
  tt<- writeRaster(result, filename= (paste(direc2,filename,".asc",sep="")),format="ascii",
overwrite = TRUE)
# save result as figure (for report)
  graphics.off();
```

```
  filen <- paste(direc2,filename,".png",sep="")
  png(filen, width=1000, height=1000);
  plot(result)
  dev.off();

###
# Periode:  najaar  (NJ)

# Variable list:
  # Depth        = lokale waterdiepte (m)
  # Secci_m      = doorzicht (m) (zelf gemeten tijdens trek)
  # Sed_med_phi  = mediane korrelgrootte sediment (phi)

# Create raster maps
Depth       <-raster(paste(direc,"depthplus.asc",sep=""));
Secci_m     <-raster(paste(direc,"Secchi_avg.asc",sep=""));
Sed_med_phi <-raster(paste(direc,"Sed_med_phi.asc",sep=""));

# Suitability function
Solea_suit_VD_NJ<-overlay(Depth, Secci_m, Sed_med_phi,
       fun=function(Depth, Secci_m, Sed_med_phi)
       10^(0.02698+0.01345*Depth-0.16034*Secci_m+0.52013*Sed_med_phi));

#check result
result <- Solea_suit_VD_NJ
 summary(result)
 plot(result)

 filename <-"Solea_suit_VD_NJ"
# save result as asc file
  tt<- writeRaster(result, filename= (paste(direc2,filename,".asc",sep="")),format="ascii",
overwrite = TRUE)
# save result as figure (for report)
  graphics.off();
  filen <- paste(direc2,filename,".png",sep="")
  png(filen, width=1000, height=1000);
  plot(result)
  dev.off();
##########
# Reference: Tulp 2011 IMARES UNPUBLISHED DATA

# Species: Limanda limanda (schar)
# Model: density in n/ha (not validated)
# glm family used: Lineaire regressiemodellen zonder poission
## Area: Voordelta (VD)
## Periode: voorjaar  (VJ)

# Variable list:
  # Depth       = lokale waterdiepte (m)
  # Sed_med_phi = mediane korrelgrootte sediment (phi)
  # Sal_avg  = Zoutgehalte (psu)

# Create raster maps
Depth       <-raster(paste(direc,"depthplus.asc",sep=""));
Sed_med_phi <-raster(paste(direc,"Sed_med_phi.asc",sep=""));
Sal_avg_ppt  <-raster(paste(direc,"Sal_avg_ppt.asc",sep=""));

# Suitability function
Limanda_suit_VD_VJ<-overlay(Depth,Sed_med_phi,Sal_avg_ppt,
       fun=function(Depth,Sed_med_phi,Sal_psu)
       10^(-3.56668-0.32099+ (0.08319*Depth) +(0.77611*Sed_med_phi)+
(0.08825*Sal_psu)));

#check result
result <- Limanda_suit_VD_VJ
 summary(result)
 plot(result)
```

```
 filename <-"Limanda_suit_VD_VJ"
# save result as asc file
  tt<- writeRaster(result, filename= (paste(direc2,filename,".asc",sep="")),format="ascii",
overwrite = TRUE)
# save result as figure (for report)
  graphics.off();
  filen <- paste(direc2,filename,".png",sep="")
  png(filen, width=1000, height=1000);
  plot(result)
  dev.off();

##
#
# Periode:  najaar

# Variable list:
  # Depth       = lokale waterdiepte (m)
  # Sed_med_phi = mediane korrelgrootte sediment (phi)
  # Sal_psu  = Zoutgehalte (psu)

# Create raster maps
Depth       <-raster(paste(direc,"depthplus.asc",sep=""));
Sed_med_phi <-raster(paste(direc,"Sed_med_phi.asc",sep=""));
Sal_psu   <-raster(paste(direc,"Sal_avg_ppt.asc",sep=""));

# Suitability function
Limanda_suit_VD_NJ<-overlay(Depth,Sed_med_phi,Sal_psu,
       fun=function(Depth,Sed_med_phi,Sal_psu)
       10^(-3.56668+0.08319*Depth+0.77611*Sed_med_phi+0.08825*Sal_psu));
#check result
result <- Limanda_suit_VD_NJ
 summary(result)
 plot(result)

 filename <-"Limanda_suit_VD_NJ"
# save result as asc file
  tt<- writeRaster(result, filename= (paste(direc2,filename,".asc",sep="")),format="ascii",
overwrite = TRUE)
# save result as figure (for report)
  graphics.off();
  filen <- paste(direc2,filename,".png",sep="")
  png(filen, width=1000, height=1000);
  plot(result)
  dev.off();

##########
# Reference: Tulp 2011 IMARES UNPUBLISHED DATA
# Species: Platichthys flesus (bot)
# Model: density in n/ha (not validated)
# glm family used: Lineaire regressiemodellen zonder poission
## Area: Voordelta (VD)
## Periode: voorjaar + najaar (geen verschil)

# Variable list:
  # Sed_med_phi  = mediane korrelgrootte sediment (phi)
  # Sal_psu   = zoutgehalte (psu), gemiddelde

# Create raster maps
Sed_med_phi <-raster(paste(direc,"Sed_med_phi.asc",sep=""));
Sal_psu  <-raster(paste(direc,"Sal_avg_ppt.asc",sep=""));

# Suitability function
Platichthys_suit_VD<-overlay(Sed_med_phi,Sal_psu,
       fun=function(Sed_med_phi, Sal_psu)
       10^(0.33112+0.51620*Sed_med_phi-0.03311*Sal_psu));
```

```
 #check result
result <- Platichthys_suit_VD
 summary(result)
 plot(result)

 filename <- "Platichthys_suit_VD"
# save result as asc file
  tt<- writeRaster(result, filename= (paste(direc2,filename,".asc",sep="")),format="ascii",
overwrite = TRUE)
# save result as figure (for report)
  graphics.off();
  filen <- paste(direc2,filename,".png",sep="")
  png(filen, width=1000, height=1000);
  plot(result)
  dev.off();
##########
# Reference: Tulp 2011 IMARES UNPUBLISHED DATA
# Species: Merlangius merlangus (wijting)
# Model: density in n/ha (not validated)
# glm family used: Lineaire regressiemodellen zonder poission
## Area: Voordelta (VD)
## Periode: voorjaar

# Variable list:
  # Depth       = lokale waterdiepte (m)
  # Secci_m     = doorzicht (m) (zelf gemeten tijdens trek)
  # Sal_psu  = zoutgehalte (psu), gemiddelde

# Create raster maps
Depth       <-raster(paste(direc,"Depth.asc",sep=""));
Secci_m     <-raster(paste(direc,"Secchi_avg.asc",sep=""));
Sal_psu   <-raster(paste(direc,"Sal_avg_ppt.asc",sep=""));

# Suitability function
Merlangius_suit_VD_VJ<-overlay(Depth, Secci_m, Sal_psu,
       fun=function(Depth, Secci_m, Sal_psu)
       10^(2.14061+0.42926+0.07402*Depth-0.28713*Secci_m-0.04841*Sal_psu));

 #check result
result <- Merlangius_suit_VD_VJ
 summary(result)
 plot(result)

 filename <- "Merlangius_suit_VD_VJ"
# save result as asc file
  tt<- writeRaster(result, filename= (paste(direc2,filename,".asc",sep="")),format="ascii",
overwrite = TRUE)
# save result as figure (for report)
  graphics.off();
  filen <- paste(direc2,filename,".png",sep="")
  png(filen, width=1000, height=1000);
  plot(result)
  dev.off();
###
# Periode:  najaar

# Variable list:
  # Depth       = lokale waterdiepte (m)
  # Secci_m     = doorzicht (m) (zelf gemeten tijdens trek)
  # Sal_psu  = zoutgehalte (psu), gemiddelde

# Create raster maps
Depth       <-raster(paste(direc,"Depth.asc",sep=""));
Secci_m     <-raster(paste(direc,"Secchi_avg.asc",sep=""));
Sal_psu   <-raster(paste(direc,"Sal_avg_ppt.asc",sep=""));

# Suitability function
```

```
Merlangius_suit_VD_NJ<-overlay(Depth, Secci_m, Sal_psu,
       fun=function(Depth, Secci_m, Sal_psu)
       10^(2.14061+0.07402*Depth-0.28713*Secci_m-0.04841*Sal_psu));

 #check result
result <- Merlangius_suit_VD_NJ
 summary(result)
 plot(result)

 filename <- "Merlangius_suit_VD_NJ"
# save result as asc file
  tt<- writeRaster(result, filename= (paste(direc2,filename,".asc",sep="")),format="ascii",
overwrite = TRUE)
# save result as figure (for report)
  graphics.off();
  filen <- paste(direc2,filename,".png",sep="")
  png(filen, width=1000, height=1000);
  plot(result)
  dev.off();

##########
# Reference: Tulp 2011 IMARES UNPUBLISHED DATA
# Species: Goby (grondels)
# Model: density in n/ha (not validated)
# glm family used: Lineaire regressiemodellen zonder poission
## Area: Voordelta (VD)
## Periode: voorjaar

# Variable list:
  # Depth       = lokale waterdiepte (m)
  # Sed_med_phi = mediane korrelgrootte sediment (phi)

# Create raster maps
Depth       <-raster(paste(direc,"depthplus.asc",sep=""));
Sed_med_phi <-raster(paste(direc,"Sed_med_phi.asc",sep=""));

# Suitability function
Goby_suit_VD_VJ<-overlay(Depth, Sed_med_phi,
       fun=function(Depth, Sed_med_phi)
       10^(0.832814-0.431325+0.002627*Depth-0.042553*Depth+0.617340*Sed_med_phi));
#check result
result <- Goby_suit_VD_VJ
 summary(result)
 plot(result)

 filename <- "Goby_suit_VD_VJ"
# save result as asc file
  tt<- writeRaster(result, filename= (paste(direc2,filename,".asc",sep="")),format="ascii",
overwrite = TRUE)
# save result as figure (for report)
  graphics.off();
  filen <- paste(direc2,filename,".png",sep="")
  png(filen, width=1000, height=1000);
  plot(result)
  dev.off();
## Periode: najaar

# Variable list:
  # Depth       = lokale waterdiepte (m)
  # Sed_med_phi = mediane korrelgrootte sediment (phi)

# Create raster maps
Depth       <-raster(paste(direc,"Depth.asc",sep=""));
Sed_med_phi <-raster(paste(direc,"Sed_med_phi.asc",sep=""));

# Suitability function
Goby_suit_VD_NJ<-overlay(Depth, Sed_med_phi,
```

```
       fun=function(Depth, Sed_med_phi)
       10^(0.832814+0.002627*Depth+0.617340*Sed_med_phi))
#check result
result <- Goby_suit_VD_NJ
 summary(result)
 plot(result)

 filename <- "Goby_suit_VD_NJ"
# save result as asc file
  tt<- writeRaster(result, filename= (paste(direc2,filename,".asc",sep="")),format="ascii",
overwrite = TRUE)
# save result as figure (for report)
  graphics.off();
  filen <- paste(direc2,filename,".png",sep="")
  png(filen, width=1000, height=1000);
  plot(result)
  dev.off();




############################################################
# DFS
############################################################
# Reference: Tulp 2011 IMARES UNPUBLISHED DATA
# Species: Pleuronectus platessa(schol)
# Model: density in n/ha (not validated)
# glm family used: Lineaire regressiemodellen zonder poission
## Area: Noordzee Kustzone (NZK)
## Periode: najaar (er is geen formule voor voorjaar)

# Variable list:
  # Depth       = lokale waterdiepte (m)
  # Secci_m     = doorzicht (m) (zelf gemeten tijdens trek)

# Create raster maps
Depth       <-raster(paste(direc,"depthplus.asc",sep=""));
Secci_m     <-raster(paste(direc,"SeccHi_avg.asc",sep=""));

# Suitability function
Pleuronectus_suit_NZK_NJ<-overlay(Depth, Secci_m,
       fun=function(Depth, Secci_m)
       10^(2.30416-0.98586-0.05979*Depth+0.11935*Depth-0.14850*Secci_m))

#check result
result <- Pleuronectus_suit_NZK_NJ
 summary(result)
 plot(result)

 filename <- "Pleuronectus_suit_NZK_NJ"
# save result as asc file
  tt<- writeRaster(result, filename= (paste(direc2,filename,".asc",sep="")),format="ascii",
overwrite = TRUE)
# save result as figure (for report)
  graphics.off();
  filen <- paste(direc2,filename,".png",sep="")
  png(filen, width=1000, height=1000);
  plot(result)
  dev.off();


## Area: Waddenzee(WAD)
## regio: wadkust (WK)
## Periode: najaar (er is geen formule voor voorjaar)

# Variable list:
  # Depth       = lokale waterdiepte (m)
```

```
  # Secci_m      = doorzicht (m) (zelf gemeten tijdens trek)

# Create raster maps
Depth       <-raster(paste(direc,"depthplus.asc",sep=""));
Secci_m     <-raster(paste(direc,"Secchi_avg.asc",sep=""));

# Suitability function
Pleuronectus_suit_WAD_WK_NJ<-overlay(Depth, Secci_m,
       fun=function(Depth, Secci_m)
       10^(2.30416+0.06139-0.05979*Depth+0.04331*Depth-0.14850*Secci_m))

 #check result
result <- Pleuronectus_suit_WAD_WK_NJ
 summary(result)
 plot(result)

 filename <- "Pleuronectus_suit_WAD_WK_NJ"
# save result as asc file
  tt<- writeRaster(result, filename= (paste(direc2,filename,".asc",sep="")),format="ascii",
overwrite = TRUE)
# save result as figure (for report)
  graphics.off();
  filen <- paste(direc2,filename,".png",sep="")
  png(filen, width=1000, height=1000);
  plot(result)
  dev.off();


## Area: Waddenzee(WAD)
## regio: oostelijke waddenzee (OW)
## Periode: najaar (er is geen formule voor voorjaar)

# Variable list:
  # Depth        = lokale waterdiepte (m)
  # Secci_m      = doorzicht (m) (zelf gemeten tijdens trek)

# Create raster maps
Depth       <-raster(paste(direc,"depthplus.asc",sep=""));
Secchi_m     <-raster(paste(direc,"Secchhi_avg.asc",sep=""));

# Suitability function
Pleuronectus_suit_WAD_OW_NJ<-overlay(Depth, Secci_m,
       fun=function(Depth, Secci_m)
       10^(2.30416-0.48414-0.05979*Depth+0.03065*Depth-0.14850*Secci_m))

 #check result
result <- Pleuronectus_suit_WAD_OW_NJ
 summary(result)
 plot(result)

 filename <- "Pleuronectus_suit_WAD_OW_NJ"
# save result as asc file
  tt<- writeRaster(result, filename= (paste(direc2,filename,".asc",sep="")),format="ascii",
overwrite = TRUE)
# save result as figure (for report)
  graphics.off();
  filen <- paste(direc2,filename,".png",sep="")
  png(filen, width=1000, height=1000);
  plot(result)
  dev.off();


## Area: Waddenzee(WAD)
## regio: westelijke waddenzee (WW)
## Periode: najaar (er is geen formule voor voorjaar)

# Variable list:
```

```
  # Depth       = lokale waterdiepte (m)
  # Secci_m     = doorzicht (m) (zelf gemeten tijdens trek)

# Create raster maps
Depth       <-raster(paste(direc,"depthplus.asc",sep=""));
Secchi_m     <-raster(paste(direc,"Secchi_avg.asc",sep=""));

# Suitability function
Pleuronectus_suit_WAD_WW_NJ<-overlay(Depth, Secci_m,
        fun=function(Depth, Secci_m)
        10^(2.30416-0.46604-0.05979*Depth+0.05209*Depth-0.14850*Secci_m))

 #check result
result <- Pleuronectus_suit_WAD_WW_NJ
 summary(result)
 plot(result)

 filename <- "Pleuronectus_suit_WAD_WW_NJ"
# save result as asc file
  tt<- writeRaster(result, filename= (paste(direc2,filename,".asc",sep="")),format="ascii",
overwrite = TRUE)
# save result as figure (for report)
  graphics.off();
  filen <- paste(direc2,filename,".png",sep="")
  png(filen, width=1000, height=1000);
  plot(result)
  dev.off();


##########
# Reference: Tulp 2011 IMARES UNPUBLISHED DATA

# Species: Solea solea (tong)
# Model: density in n/ha (not validated)
# glm family used: Lineaire regressiemodellen zonder poission
## Area: Noordzee Kustzone (NZK)
## Periode: najaar (er is geen formule voor voorjaar)

# Variable list:
  # Depth       = lokale waterdiepte (m)
  # Secci_m     = doorzicht (m) (zelf gemeten tijdens trek)

# Create raster maps
Depth       <-raster(paste(direc,"depthplus.asc",sep=""));
Secchi_m     <-raster(paste(direc,"Secchi_avg.asc",sep=""));

# Suitability function
Solea_suit_NZK_NJ<-overlay(Depth, Secci_m,
        fun=function(Depth, Secci_m)
        10^(1.33309-0.87370-0.02483*Depth+0.07294*Depth-0.26212*Secci_m))
 #check result
result <- Solea_suit_NZK_NJ
 summary(result)
 plot(result)

 filename <- "Solea_suit_NZK_NJ"
# save result as asc file
  tt<- writeRaster(result, filename= (paste(direc2,filename,".asc",sep="")),format="ascii",
overwrite = TRUE)
# save result as figure (for report)
  graphics.off();
  filen <- paste(direc2,filename,".png",sep="")
  png(filen, width=1000, height=1000);
  plot(result)
  dev.off();

## Area: Waddenzee(WAD)
```

```
## regio: wadkust (WK)
## Periode: najaar (er is geen formule voor voorjaar)

# Variable list:
  # Depth       = lokale waterdiepte (m)
  # Secci_m     = doorzicht (m) (zelf gemeten tijdens trek)

# Create raster maps
Depth       <-raster(paste(direc,"depthplus.asc",sep=""));
Secci_m     <-raster(paste(direc,"Secchi_avg.asc",sep=""));

# Suitability function
Solea_suit_WAD_WK_NJ<-overlay(Depth, Secci_m,
        fun=function(Depth, Secci_m)
        10^(1.33309-0.60920-0.02483*Depth+0.03071*Depth-0.26212*Secci_m))
 #check result
result <- Solea_suit_WAD_WK_NJ
 summary(result)
 plot(result)

 filename <- "Solea_suit_WAD_WK_NJ"
# save result as asc file
  tt<- writeRaster(result, filename= (paste(direc2,filename,".asc",sep="")),format="ascii",
overwrite = TRUE)
# save result as figure (for report)
  graphics.off();
  filen <- paste(direc2,filename,".png",sep="")
  png(filen, width=1000, height=1000);
  plot(result)
  dev.off();

## Area: Waddenzee(WAD)
## regio: oostelijke waddenzee (OW)
## Periode: najaar (er is geen formule voor voorjaar)

# Variable list:
  # Depth       = lokale waterdiepte (m)
  # Secci_m     = doorzicht (m) (zelf gemeten tijdens trek)

# Create raster maps
Depth       <-raster(paste(direc,"depthplus.asc",sep=""));
Secci_m     <-raster(paste(direc,"Secchi_avg.asc",sep=""));

# Suitability function
Solea_suit_WAD_OW_NJ<-overlay(Depth, Secci_m,
        fun=function(Depth, Secci_m)
        10^(1.33309-0.40760-0.02483*Depth+0.06204*Depth-0.26212*Secci_m))
 #check result
result <- Solea_suit_WAD_OW_NJ
 summary(result)
 plot(result)

 filename <- "Solea_suit_WAD_OW_NJ"
# save result as asc file
  tt<- writeRaster(result, filename= (paste(direc2,filename,".asc",sep="")),format="ascii",
overwrite = FALSE)
# save result as figure (for report)
  graphics.off();
  filen <- paste(direc2,filename,".png",sep="")
  png(filen, width=1000, height=1000);
  plot(result)
  dev.off();

## Area: Waddenzee(WAD)
## regio: westelijke waddenzee (WW)
## Periode: najaar (er is geen formule voor voorjaar)
```

```
# Variable list:
  # Depth       = lokale waterdiepte (m)
  # Secci_m     = doorzicht (m) (zelf gemeten tijdens trek)

# Create raster maps
Depth       <-raster(paste(direc,"depthplus.asc",sep=""));
Secci_m     <-raster(paste(direc,"Secchi_avg.asc",sep=""));

# Suitability function
Solea_suit_WAD_WW_NJ<-overlay(Depth, Secci_m,
        fun=function(Depth, Secci_m)
        10^(1.33309-0.85293-0.02483*Depth+0.06298*Depth-0.26212*Secci_m))
 #check result
result <- Solea_suit_WAD_WW_NJ
 summary(result)
 plot(result)

 filename <- "Solea_suit_WAD_WW_NJ"
# save result as asc file
  tt<- writeRaster(result, filename= (paste(direc2,filename,".asc",sep="")),format="ascii",
overwrite = FALSE)
# save result as figure (for report)
  graphics.off();
  filen <- paste(direc2,filename,".png",sep="")
  png(filen, width=1000, height=1000);
  plot(result)
  dev.off();

##########
# Reference: Tulp 2011 IMARES UNPUBLISHED DATA

# Species: Limanda limanda (schar)
# Model: density in n/ha (not validated)
# glm family used: Lineaire regressiemodellen zonder poission
## Area: Noordzee Kustzone (NZK)
## Periode: najaar (er is geen formule voor voorjaar)

# Variable list:
  # Depth       = lokale waterdiepte (m)

# Create raster maps
Depth       <-raster(paste(direc,"depthplus.asc",sep=""));

# Suitability function
Limanda_suit_NZK_NJ<-overlay(Depth,
        fun=function(Depth)
        10^(0.126657+1.261032+0.017605*Depth) )
 #check result
result <- Limanda_suit_NZK_NJ
 summary(result)
 plot(result)

 filename <- "Limanda_suit_NZK_NJ"
# save result as asc file
  tt<- writeRaster(result, filename= (paste(direc2,filename,".asc",sep="")),format="ascii",
overwrite = FALSE)
# save result as figure (for report)
  graphics.off();
  filen <- paste(direc2,filename,".png",sep="")
  png(filen, width=1000, height=1000);
  plot(result)
  dev.off();
## Area: Waddenzee(WAD)
## regio: wadkust (WK)
## Periode: najaar (er is geen formule voor voorjaar)

# Variable list:
```

```
  # Depth       = lokale waterdiepte (m)

# Create raster maps
Depth       <-raster(paste(direc,"depthplus.asc",sep=""));

# Suitability function
Limanda_suit_WAD_WK_NJ<-overlay(Depth,
       fun=function(Depth)
       10^(0.126657+0.978218+0.017605*Depth))
 #check result
result <- Limanda_suit_WAD_WK_NJ
 summary(result)
 plot(result)

 filename <- "Limanda_suit_WAD_WK_NJ"
# save result as asc file
  tt<- writeRaster(result, filename= (paste(direc2,filename,".asc",sep="")),format="ascii",
overwrite = FALSE)
# save result as figure (for report)
  graphics.off();
  filen <- paste(direc2,filename,".png",sep="")
  png(filen, width=1000, height=1000);
  plot(result)
  dev.off();
## Area: Waddenzee(WAD)
## regio: oostelijke waddenzee (OW)
## Periode: najaar (er is geen formule voor voorjaar)

# Variable list:
  # Depth       = lokale waterdiepte (m)

# Create raster maps
Depth       <-raster(paste(direc,"depthplus.asc",sep=""));

# Suitability function
Limanda_suit_WAD_OW_NJ<-overlay(Depth,
       fun=function(Depth)
       10^(0.126657-0.052435+0.017605*Depth))
 #check result
result <- Limanda_suit_WAD_OW_NJ
 summary(result)
 plot(result)

 filename <- "Limanda_suit_WAD_OW_NJ"
# save result as asc file
  tt<- writeRaster(result, filename= (paste(direc2,filename,".asc",sep="")),format="ascii",
overwrite = FALSE)
# save result as figure (for report)
  graphics.off();
  filen <- paste(direc2,filename,".png",sep="")
  png(filen, width=1000, height=1000);
  plot(result)
  dev.off();

## Area: Waddenzee(WAD)
## regio: westelijke waddenzee (WW)
## Periode: najaar (er is geen formule voor voorjaar)

# Variable list:
  # Depth       = lokale waterdiepte (m)

# Create raster maps
Depth       <-raster(paste(direc,"depthplus.asc",sep=""));

# Suitability function
Limanda_suit_WAD_WW_NJ<-overlay(Depth,
       fun=function(Depth)
```

```
        10^(0.126657+0.042075+0.017605*Depth))
 #check result
result <- Limanda_suit_WAD_WW_NJ
 summary(result)
 plot(result)

 filename <- "Limanda_suit_WAD_WW_NJ"
# save result as asc file
  tt<- writeRaster(result, filename= (paste(direc2,filename,".asc",sep="")),format="ascii",
overwrite = FALSE)
# save result as figure (for report)
  graphics.off();
  filen <- paste(direc2,filename,".png",sep="")
  png(filen, width=1000, height=1000);
  plot(result)
  dev.off();

##########
# Reference: Tulp 2011 IMARES UNPUBLISHED DATA
# Species: Platichthys flesus (bot)
# Model: density in n/ha (not validated)
# glm family used: Lineaire regressiemodellen zonder poissíon
## Area: Noordzee Kustzone (NZK)
## Periode: najaar (er is geen formule voor voorjaar)

# Variable list:
  # Depth       = lokale waterdiepte (m)
  # Secci_m      = doorzicht (m) (zelf gemeten tijdens trek)

# Create raster maps
Depth       <-raster(paste(direc,"depthplus.asc",sep=""));
Secci_m      <-raster(paste(direc,"Secchi_avg.asc",sep=""));

# Suitability function
Platichthys_suit_NZK_NJ<-overlay(Depth, Secci_m,
        fun=function(Depth, Secci_m)
        10^(1.47914-1.06961-0.06078*Depth + 0.07805*Depth-0.20147*Secci_m))
 #check result
result <- Platichthys_suit_NZK_NJ
 summary(result)
 plot(result)

 filename <- "Platichthys_suit_NZK_NJ"
# save result as asc file
  tt<- writeRaster(result, filename= (paste(direc2,filename,".asc",sep="")),format="ascii",
overwrite = FALSE)
# save result as figure (for report)
  graphics.off();
  filen <- paste(direc2,filename,".png",sep="")
  png(filen, width=1000, height=1000);
  plot(result)
  dev.off();
## Area: Waddenzee(WAD)
## regio: wadkust (WK)
## Periode: najaar (er is geen formule voor voorjaar)

# Variable list:
  # Depth       = lokale waterdiepte (m)
  # Secci_m      = doorzicht (m) (zelf gemeten tijdens trek)

# Create raster maps
Depth       <-raster(paste(direc,"depthplus.asc",sep=""));
Secci_m      <-raster(paste(direc,"Secchi_avg.asc",sep=""));

# Suitability function
Platichthys_suit_WAD_WK_NJ<-overlay(Depth, Secci_m,
        fun=function(Depth, Secci_m)
```

```
      10^(1.47914-1.25027-0.06078*Depth + 0.07910*Depth-0.20147*Secci_m))
 #check result
result <- Platichthys_suit_WAD_WK_NJ
 summary(result)
 plot(result)

 filename <- "Platichthys_suit_WAD_WK_NJ"
# save result as asc file
  tt<- writeRaster(result, filename= (paste(direc2,filename,".asc",sep="")),format="ascii",
overwrite = FALSE)
# save result as figure (for report)
  graphics.off();
  filen <- paste(direc2,filename,".png",sep="")
  png(filen, width=1000, height=1000);
  plot(result)
  dev.off();

## Area: Waddenzee(WAD)
## regio: oostelijke waddenzee (OW)
## Periode: najaar (er is geen formule voor voorjaar)

# Variable list:
  # Depth       = lokale waterdiepte (m)
  # Secci_m     = doorzicht (m) (zelf gemeten tijdens trek)

# Create raster maps
Depth       <-raster(paste(direc,"depthplus.asc",sep=""));
Secci_m     <-raster(paste(direc,"Secchi_avg.asc",sep=""));

# Suitability function
Platichthys_suit_WAD_OW_NJ<-overlay(Depth, Secci_m,
      fun=function(Depth, Secci_m)
      10^(1.47914-0.28082-0.06078*Depth + 0.04342*Depth-0.20147*Secci_m))
 #check result
result <- Platichthys_suit_WAD_OW_NJ
 summary(result)
 plot(result)

 filename <- "Platichthys_suit_WAD_OW_NJ"
# save result as asc file
  tt<- writeRaster(result, filename= (paste(direc2,filename,".asc",sep="")),format="ascii",
overwrite = FALSE)
# save result as figure (for report)
  graphics.off();
  filen <- paste(direc2,filename,".png",sep="")
  png(filen, width=1000, height=1000);
  plot(result)
  dev.off();

## Area: Waddenzee(WAD)
## regio: westelijke waddenzee (WW)
## Periode: najaar (er is geen formule voor voorjaar)

# Variable list:
  # Depth       = lokale waterdiepte (m)
  # Secci_m     = doorzicht (m) (zelf gemeten tijdens trek)

# Create raster maps
Depth       <-raster(paste(direc,"depthplus.asc",sep=""));
Secci_m     <-raster(paste(direc,"Secchi_avg.asc",sep=""));

# Suitability function
Platichthys_suit_WAD_WW_NJ<-overlay(Depth, Secci_m,
      fun=function(Depth, Secci_m)
      10^(1.47914-0.65339-0.06078*Depth + 0.04478*Depth-0.20147*Secci_m))
 #check result
result <- Platichthys_suit_WAD_WW_NJ
```

```
 summary(result)
 plot(result)

 filename <- "Platichthys_suit_WAD_WW_NJ"
# save result as asc file
  tt<- writeRaster(result, filename= (paste(direc2,filename,".asc",sep="")),format="ascii",
overwrite = FALSE)
# save result as figure (for report)
  graphics.off();
  filen <- paste(direc2,filename,".png",sep="")
  png(filen, width=1000, height=1000);
  plot(result)
  dev.off();

##########
# Reference: Tulp 2011 IMARES UNPUBLISHED DATA

# Species: Merlangius merlangus (wijting)
# Model: density in n/ha (not validated)
# glm family used: Lineaire regressiemodellen zonder poission
## Area: Noordzee Kustzone (NZK)
## Periode: najaar (er is geen formule voor voorjaar)

# Variable list:
  # Depth       = lokale waterdiepte (m)
  # Secci_m     = doorzicht (m) (zelf gemeten tijdens trek)

# Create raster maps
Depth       <-raster(paste(direc,"depthplus.asc",sep=""));
Secci_m     <-raster(paste(direc,"Secchi_avg.asc",sep=""));

# Suitability function
Merlangius_suit_NZK_NJ<-overlay(Depth, Secci_m,
       fun=function(Depth, Secci_m)
       10^(-0.107840+0.585360+0.067099*Depth - 0.024864*Depth-0.098863*Secci_m))
 #check result
result <- Merlangius_suit_NZK_NJ
 summary(result)
 plot(result)

 filename <- "Merlangius_suit_NZK_NJ"
# save result as asc file
  tt<- writeRaster(result, filename= (paste(direc2,filename,".asc",sep="")),format="ascii",
overwrite = TRUE)
# save result as figure (for report)
  graphics.off();
  filen <- paste(direc2,filename,".png",sep="")
  png(filen, width=1000, height=1000);
  plot(result)
  dev.off();

## Area: Waddenzee(WAD)
## regio: wadkust (WK)
## Periode: najaar (er is geen formule voor voorjaar)

# Variable list:
  # Depth       = lokale waterdiepte (m)
  # Secci_m     = doorzicht (m) (zelf gemeten tijdens trek)

# Create raster maps
Depth       <-raster(paste(direc,"depthplus.asc",sep=""));
Secci_m     <-raster(paste(direc,"Secchi_avg.asc",sep=""));

# Suitability function
Merlangius_suit_WAD_WK_NJ<-overlay(Depth, Secci_m,
       fun=function(Depth, Secci_m)
       10^(-0.107840+1.296552+0.067099*Depth - 0.077458*Depth-0.098863*Secci_m))
```

```
 #check result
result <- Merlangius_suit_WAD_WK_NJ
 summary(result)
 plot(result)

 filename <- "Merlangius_suit_WAD_WK_NJ"
# save result as asc file
  tt<- writeRaster(result, filename= (paste(direc2,filename,".asc",sep="")),format="ascii",
overwrite = TRUE)
# save result as figure (for report)
  graphics.off();
  filen <- paste(direc2,filename,".png",sep="")
  png(filen, width=1000, height=1000);
  plot(result)
  dev.off();

## Area: Waddenzee(WAD)
## regio: oostelijke waddenzee (OW)
## Periode: najaar (er is geen formule voor voorjaar)

# Variable list:
  # Depth       = lokale waterdiepte (m)
  # Secci_m     = doorzicht (m) (zelf gemeten tijdens trek)

# Create raster maps
Depth       <-raster(paste(direc,"depthplus.asc",sep=""));
Secci_m     <-raster(paste(direc,"Secchi_avg.asc",sep=""));

# Suitability function
Merlangius_suit_WAD_OW_NJ<-overlay(Depth, Secci_m,
       fun=function(Depth, Secci_m)
       10^(-0.107840+0.214750+0.067099*Depth - 0.008324*Depth-0.098863*Secci_m))
 #check result
result <- Merlangius_suit_WAD_OW_NJ
 summary(result)
 plot(result)

 filename <- "Merlangius_suit_WAD_OW_NJ"
# save result as asc file
  tt<- writeRaster(result, filename= (paste(direc2,filename,".asc",sep="")),format="ascii",
overwrite = FALSE)
# save result as figure (for report)
  graphics.off();
  filen <- paste(direc2,filename,".png",sep="")
  png(filen, width=1000, height=1000);
  plot(result)
  dev.off();

## Area: Waddenzee(WAD)
## regio: westelijke waddenzee (WW)
## Periode: najaar (er is geen formule voor voorjaar)

# Variable list:
  # Depth       = lokale waterdiepte (m)
  # Secci_m     = doorzicht (m) (zelf gemeten tijdens trek)

# Create raster maps
Depth       <-raster(paste(direc,"depthplus.asc",sep=""));
Secci_m     <-raster(paste(direc,"Secchi_avg.asc",sep=""));

# Suitability function
Merlangius_suit_WAD_WW_NJ<-overlay(Depth, Secci_m,
       fun=function(Depth, Secci_m)
        10^(-0.107840+0.0093921+0.067099*Depth - 0.018403*Depth-0.098863*Secci_m))
 #check result
result <- Merlangius_suit_WAD_WW_NJ
 summary(result)
```

```
 plot(result)

 filename <- "Merlangius_suit_WAD_WW_NJ"
# save result as asc file
  tt<- writeRaster(result, filename= (paste(direc2,filename,".asc",sep="")),format="ascii",
overwrite = FALSE)
# save result as figure (for report)
  graphics.off();
  filen <- paste(direc2,filename,".png",sep="")
  png(filen, width=1000, height=1000);
  plot(result)
  dev.off();

##########
# Reference: Tulp 2011 IMARES UNPUBLISHED DATA
# Species: Gomby (grondels)
# Model: density in n/ha (not validated)
# glm family used: Lineaire regressiemodellen zonder poission
## Area: Noordzee Kustzone (NZK)
## Periode: najaar (er is geen formule voor voorjaar)

# Variable list:
  # Depth       = lokale waterdiepte (m)
  # Secci_m     = doorzicht (m) (zelf gemeten tijdens trek)

# Create raster maps
Depth       <-raster(paste(direc,"depthplus.asc",sep=""));
Secci_m     <-raster(paste(direc,"Secchi_avg.asc",sep=""));

# Suitability function
Goby_suit_NZK_NJ<-overlay(Depth, Secci_m,
       fun=function(Depth, Secci_m)
       10^(1.43604+1.58536+0.01553*Depth+0.00230*Depth-0.24775*Secci_m))

#check result
result <- Goby_suit_NZK_NJ
 summary(result)
 plot(result)

 filename <- "Goby_suit_NZK_NJ"
# save result as asc file
  tt<- writeRaster(result, filename= (paste(direc2,filename,".asc",sep="")),format="ascii",
overwrite = FALSE)
# save result as figure (for report)
  graphics.off();
  filen <- paste(direc2,filename,".png",sep="")
  png(filen, width=1000, height=1000);
  plot(result)
  dev.off();
## Area: Waddenzee(WAD)
## regio: wadkust (WK)
## Periode: najaar (er is geen formule voor voorjaar)

# Variable list:
  # Depth       = lokale waterdiepte (m)
  # Secci_m     = doorzicht (m) (zelf gemeten tijdens trek)

# Create raster maps
Depth       <-raster(paste(direc,"depthplus.asc",sep=""));
Secci_m     <-raster(paste(direc,"Secchi_avg.asc",sep=""));

# Suitability function
Goby_suit_WAD_WK_NJ<-overlay(Depth, Secci_m,
       fun=function(Depth, Secci_m)
       10^(1.43604+1.57019+0.01553*Depth-0.01476*Depth-0.24775*Secci_m))

#check result
```

```
result <- Goby_suit_WAD_WK_NJ
 summary(result)
 plot(result)

 filename <- "Goby_suit_WAD_WK_NJ"
# save result as asc file
  tt<- writeRaster(result, filename= (paste(direc2,filename,".asc",sep="")),format="ascii",
overwrite = FALSE)
# save result as figure (for report)
  graphics.off();
  filen <- paste(direc2,filename,".png",sep="")
  png(filen, width=1000, height=1000);
  plot(result)
  dev.off();

## Area: Waddenzee(WAD)
## regio: oostelijke waddenzee (OW)
## Periode: najaar (er is geen formule voor voorjaar)

# Variable list:
  # Depth       = lokale waterdiepte (m)
  # Secci_m     = doorzicht (m) (zelf gemeten tijdens trek)

# Create raster maps
Depth       <-raster(paste(direc,"depthplus.asc",sep=""));
Secci_m     <-raster(paste(direc,"Secchi_avg.asc",sep=""));

# Suitability function
Goby_suit_WAD_OW_NJ<-overlay(Depth, Secci_m,
        fun=function(Depth, Secci_m)
        10^(1.43604+0.56890+0.01553*Depth-0.07626*Depth-0.24775*Secci_m))

#check result
result <- Goby_suit_WAD_OW_NJ
 summary(result)
 plot(result)

 filename <- "Goby_suit_WAD_OW_NJ"
# save result as asc file
  tt<- writeRaster(result, filename= (paste(direc2,filename,".asc",sep="")),format="ascii",
overwrite = FALSE)
# save result as figure (for report)
  graphics.off();
  filen <- paste(direc2,filename,".png",sep="")
  png(filen, width=1000, height=1000);
  plot(result)
  dev.off();

## Area: Waddenzee(WAD)
## regio: westelijke waddenzee (WW)
## Periode: najaar (er is geen formule voor voorjaar)

# Variable list:
  # Depth       = lokale waterdiepte (m)
  # Secci_m     = doorzicht (m) (zelf gemeten tijdens trek)

# Create raster maps
Depth       <-raster(paste(direc,"depthplus.asc",sep=""));
Secci_m     <-raster(paste(direc,"Secchi_avg.asc",sep=""));

# Suitability function
Goby_suit_WAD_WW_NJ<-overlay(Depth, Secci_m,
        fun=function(Depth, Secci_m)
        10^(1.43604+0.38243+0.01553*Depth-0.04341*Depth-0.24775*Secci_m))

#check result
result <- Goby_suit_WAD_WW_NJ
```

```
 summary(result)
 plot(result)

 filename <- "Goby_suit_WAD_WW_NJ"
# save result as asc file
  tt<- writeRaster(result, filename= (paste(direc2,filename,".asc",sep="")),format="ascii",
overwrite = FALSE)
# save result as figure (for report)
  graphics.off();
  filen <- paste(direc2,filename,".png",sep="")
  png(filen, width=1000, height=1000);
  plot(result)
  dev.off();
# IMARES
```

Appendix C: Bird suitability models – R code

```
##########################################################
# Habitat suitability models based on raster maps
# IMARES
# date:5-3-2012
##########################################################


##########################################################
# Initial settings
##########################################################

# clear memory
rm(list=(ls()));

# load packages
library(raster) # for raster/grid algebra
library(sp)
library(lattice)
library(maptools)
library(rgdal)

# set home dir
direc  <-"N:/Projecten/Building with Nature - Habitat inventory/Model/input_maps_shallow/";
direc2  <-"N:/Projecten/Building with Nature - Habitat inventory/Model/results_birds/";


##########################################################
# Birds
##########################################################



#######
# suitability functions per bird species
#######

### Toppereend

# reference: Excel sheet by Richard Witte "Habitateisen zeezoogdieren en zeevogels" IMARES
# species:  Toppereend/ Aythya marila
# model:Geschiktheidsregels
# variable:water depth (m)

# create raster maps
depth     <- raster(paste(direc,"depthplus.asc",sep=""));

## suitability function
 Aythya_water_depth    <- reclass(depth, c(0,5,1,  5,15,0.5, 15.1,Inf,0))

#check result
result <-  Aythya_water_depth
 summary(result)
 plot(result)

 filename <- " Aythya_water_depth"
# save result as asc file

  tt<- writeRaster(result, filename= (paste(direc2,filename,".asc",sep="")),format="ascii",
overwrite = FALSE)
```

```
# save result as figure (for report)
  graphics.off();
  filen <- paste(direc2,filename,".png",sep="")
  png(filen, width=1000, height=1000);
  plot(result)
  dev.off();


### Eidereend

# reference: Excel sheet by Richard Witte "Habitateisen zeezoogdieren en zeevogels" IMARES
# species:  Eidereend/ Somateria mollissima
# model:Geschiktheidsregels
# variable:water depth (m)


# create raster maps
depth     <- raster(paste(direc,"depthplus.asc",sep=""));

## suitability function
 Somateria_water_depth    <- reclass(depth, c(0,5,1,  5,20,0.5, 20.1,Inf,0))

#check result
result <- Somateria_water_depth
 summary(result)
 plot(result)

 filename <- "Somateria_water_depth"
# save result as asc file

  tt<- writeRaster(result, filename= (paste(direc2,filename,".asc",sep="")),format="ascii",
overwrite = FALSE)
# save result as figure (for report)
  graphics.off();
  filen <- paste(direc2,filename,".png",sep="")
  png(filen, width=1000, height=1000);
  plot(result)
  dev.off();


### IJseend

# reference: Excel sheet by Richard Witte "Habitateisen zeezoogdieren en zeevogels" IMARES
# species: IJseend/ Clangula hyemalis
# model:Geschiktheidsregels
# variable: water depth (m)

# create raster maps
depth     <- raster(paste(direc,"depthplus.asc",sep=""));

## suitability function
clangula_water_depth    <- reclass(depth, c(0,6,0, 6,15,1, 15,20,0.5, 20.1,Inf,0))

#check result
result <- clangula_water_depth
 summary(result)
 plot(result)

 filename <- "clangula_water_depth"
# save result as asc file
```

```
  tt<- writeRaster(result, filename= (paste(direc2,filename,".asc",sep="")),format="ascii",
overwrite = FALSE)
# save result as figure (for report)
  graphics.off();
  filen <- paste(direc2,filename,".png",sep="")
  png(filen, width=1000, height=1000);
  plot(result)
  dev.off();


### Zwarte zee-eend

# reference: Excel sheet by Richard Witte "Habitateisen zeezoogdieren en zeevogels" IMARES
# species:  Zwarte zee-eend/ Melanitta nigra
# model:Geschiktheidsregels
# variable: water depth (m)

# create raster maps
depth     <- raster(paste(direc,"depthplus.asc",sep=""));

## suitability function
 Melanitta_nigra_water_depth    <- reclass(depth, c(0,5,0, 5,15,1, 15,30,0.5, 30.1,Inf,0))

#check result
result <- Melanitta_nigra_water_depth
 summary(result)
 plot(result)

 filename <- "Melanitta_nigra_water_depth"
# save result as asc file

  tt<- writeRaster(result, filename= (paste(direc2,filename,".asc",sep="")),format="ascii",
overwrite = FALSE)
# save result as figure (for report)
  graphics.off();
  filen <- paste(direc2,filename,".png",sep="")
  png(filen, width=1000, height=1000);
  plot(result)
  dev.off();


###   Grote zee-eend

# reference: Excel sheet by Richard Witte "Habitateisen zeezoogdieren en zeevogels" IMARES
# species:  Grote zee-eend/ Melanitta fusca
# model:Geschiktheidsregels
# variable: water depth (m)

# create raster maps
depth     <- raster(paste(direc,"depthplus.asc",sep=""));

## suitability function
 Melanitta_fusca_water_depth    <- reclass(depth, c(0,5,0, 5,15,1, 15,20,0.5, 20.1,Inf,0))

#check result
result <- Melanitta_fusca_water_depth
 summary(result)
 plot(result)

 filename <- "Melanitta_fusca_water_depth "
# save result as asc file
```

```
 tt<- writeRaster(result, filename= (paste(direc2,filename,".asc",sep="")),format="ascii",
overwrite = FALSE)
# save result as figure (for report)
 graphics.off();
 filen <- paste(direc2,filename,".png",sep="")
 png(filen, width=1000, height=1000);
 plot(result)
 dev.off();


###  Noordse stormvogel

# reference: Excel sheet by Richard Witte "Habitateisen zeezoogdieren en zeevogels" IMARES
# species: Fulmarus glacialis/ Noordse stormvogel
# model:Geschiktheidsregels
# variable: surface salinity (mg/l)

# create raster maps
surface_salinity     <- raster(paste(direc,"sal_avg_ppt.asc",sep=""));

## suitability function
 Fulmar_surface_salinity     <- reclass(surface_salinity, c(0,29,0, 29,33,0.5, 33,35,1,
35.1,Inf,0))

#check result
result <- Fulmar_surface_salinity
 summary(result)
 plot(result)

 filename <- "Fulmar_surface_salinity"
# save result as asc file

 tt<- writeRaster(result, filename= (paste(direc2,filename,".asc",sep="")),format="ascii",
overwrite = FALSE)
# save result as figure (for report)
 graphics.off();
 filen <- paste(direc2,filename,".png",sep="")
 png(filen, width=1000, height=1000);
 plot(result)
 dev.off();


### Zeekoet

# reference: Excel sheet by Richard Witte "Habitateisen zeezoogdieren en zeevogels" IMARES
# species: Zeekoet/ Uria aalge
# model:Geschiktheidsregels
# variable: surface salinity (mg/l)

# create raster maps
surface_salinity     <- raster(paste(direc,"sal_avg_ppt.asc",sep=""));
## suitability function
 Guillemot_surface_salinity     <- reclass(surface_salinity, c(0,29,0, 29,31,0.5, 31,35,1,
35.1,Inf,0))

#check result
result <- Guillemot_surface_salinity
 summary(result)
 plot(result)

 filename <- "Guillemot_surface_salinity"
# save result as asc file
```

```
  tt<- writeRaster(result, filename= (paste(direc2,filename,".asc",sep="")),format="ascii",
overwrite = FALSE)
# save result as figure (for report)
  graphics.off();
  filen <- paste(direc2,filename,".png",sep="")
  png(filen, width=1000, height=1000);
  plot(result)
  dev.off();


### Stormmeeuw

# reference: Excel sheet by Richard Witte "Habitateisen zeezoogdieren en zeevogels" IMARES
# species: Stormmeeuw/ Larus canus
# model:Geschiktheidsregels
# variable: surface salinity (mg/l)

# create raster maps
surface_salinity     <- raster(paste(direc,"sal_avg_ppt.asc",sep=""));

## suitability function
 Common_gull_surface_salinity    <- reclass(surface_salinity, c(0,29,0, 29,30,1, 30,35,0.5,
35.1,Inf,0))

#check result
result <- Common_gull_surface_salinity
 summary(result)
 plot(result)

 filename <- "Common_gull_surface_salinity"
# save result as asc file

  tt<- writeRaster(result, filename= (paste(direc2,filename,".asc",sep="")),format="ascii",
overwrite = FALSE)
# save result as figure (for report)
  graphics.off();
  filen <- paste(direc2,filename,".png",sep="")
  png(filen, width=1000, height=1000);
  plot(result)
  dev.off();

### Drieteenmeeuw

# reference: Excel sheet by Richard Witte "Habitateisen zeezoogdieren en zeevogels" IMARES
# species: Drieteenmeeuw/ Rissa tridactyla
# model:Geschiktheidsregels
# variable: surface salinity (mg/l)

# create raster maps
surface_salinity     <- raster(paste(direc,"sal_avg_ppt.asc",sep=""));

## suitability function
Kittiwake_surface_salinity    <- reclass(surface_salinity, c(0,29,0, 29,31,0.5, 31,33,1,
33,35,0.5, 35.1,Inf,0))

#check result
result <- Kittiwake_surface_salinity
 summary(result)
 plot(result)

 filename <- "Kittiwake_surface_salinity"
```

```
# save result as asc file

  tt<- writeRaster(result, filename= (paste(direc2,filename,".asc",sep="")),format="ascii",
overwrite = FALSE)
# save result as figure (for report)
  graphics.off();
  filen <- paste(direc2,filename,".png",sep="")
  png(filen, width=1000, height=1000);
  plot(result)
  dev.off();


##########################################################
# Sandwich Tern
##########################################################
# reference: Baptist MJ & Leopold MF. 2007. Vangstsucces van de Grote Sterns van De
# Petten, Texel. IMARES Report C097.

#de relatie tussen zichtdiepte en vangstsucces van de grote sterns van de Petten, Texel.
#IMARES
# species:  Grote stern/ Thalasseus sandvicensis
# model:Geschiktheidsregels
# area: concerns the colony "de Petten" on Texel. area of applicication unknown.
# variable: water depth (m)
# variable: secchi depth

# create raster maps
depth     <- raster(paste(direc,"depthplus.asc",sep=""));
secchi     <- raster(paste(direc,"Secchi_avg.asc",sep=""));

## suitability functions
 Tern_water_depth    <- reclass(depth, c(0,3,0.5,  3,6,1, 6,25,0.5, 25.1,Inf,0))
 Tern_secchi_depth    <- reclass(secchi, c(0,0.25,0, 0.25,1.5,0.5,  1.5,2,1, 2,3.5,0.5,
3.51,Inf,0))

## final suitability is minimal suitability value of both variables combined.
tern_final_hsi <- min(Tern_water_depth,Tern_secchi_depth)

#check result
result <- tern_final_hsi
 summary(result)
 plot(result)
result[result < 0 ] <-0

 filename <- "Tern_final-hsi"

# save result as asc file
tt<- writeRaster(result, filename= (paste(direc2,filename,".asc",sep="")),format="ascii",
overwrite = FALSE)

# save result as figure (for report)
  graphics.off();
  filen <- paste(direc2,filename,".png",sep="")
  png(filen, width=1000, height=1000);
  plot(result)
  dev.off();
# IMARES
```

Appendix D: Mammal suitability models - R code

```
#################################################################
# Habitat suitability models based on raster maps
# Mammals
# IMARES
# date: November 2011
#################################################################


#################################################################
# Initial settings
#################################################################

# clear memory
rm(list=(ls()));

# load packages
library(raster) # for raster/grid algebra
library(sp)
library(lattice)
library(maptools)

# set home dir
direc<-"D:/UserData/projekten/building with nature/Rspatial/";


#################################################################
# Harbor Porpoise
#################################################################

######################
# Reference: Expert Judgement Richard Witte IMARES
# Species: Phocoena phocoena - Harbor porpoise (bruinvis)
# Model: geschiktheidsregels
# Kennisregels
# Area: Noordzee kust

# Variable list:
  # Current_speed  = golfsnelheid (m/s) > velocity
  # Waterdepth     = diepte (m)
  # Sea surface salinity = jaargemiddeld (psu)
  # Sea surface temperature = jaargemiddeld (degr. C)


# Create raster maps
Curr_speed   <-raster(paste(direc,"Current.asc",sep=""));
Depth   <-raster(paste(direc,"Depth.asc",sep=""));
Sal_avg   <-raster(paste(direc,"Sal_avg.asc",sep=""));
Temp_avg   <-raster(paste(direc,"Temp_avg.asc",sep=""));

## salinity
 Sal        <- reclass(Sal_avg, c(-Inf,31,0, 31,36,1, 36,Inf,0))
## depth
 Depth      <- reclass(Depth, c(0,5,0 5,231,1, 231,Inf,0))
## current speed
 Curr       <- reclass(Curr_speed, c(0,2.8,1, 2.8,Inf,0))
## temperature avg
 Temp       <- reclass(Temp_avg, c(0,6,0, 6,18,1, 18,Inf,0))

# Suitability function
```

```
Porpoise_hsi<-overlay(Sal, Depth, Curr, Temp,
        fun=function(Sal, Depth, Curr, Temp)
        min(Sal, Depth, Curr, Temp));


######################################################
# (Grey) Seal
######################################################

###################
# Bouma S, Lengkeek W, van den Boogaard B & Waardenburg HW. 2010. Reageren zeehonden
# op de Razende Bol op langsvarende baggerschepen? Bureau Waardenburg Report nr 09-291.
# Species:  Seal (gewone zeehond); geen gegevens grijze zeehond beschikbaar. dit geldt alleen
voor VOLWASSEN exemplaren; Minimale afstand onderwerp van discussie.
# Model: habitat suitability rules
# Kennisregels
# Area: Noordzee kust
# IMARES

# Variable list:
# seal resting places 'platen'

# create raster maps
seal      <-raster(paste(direc,"sealrest.asc",sep="")) # map with 'platen' only!!!


# distance from resting place
seal_dis <- distance(seal) # dit is een kaartje met afstanden tot 'platen'

# Suitability function
seal_dis_hsi      <- reclass(seal_dis, c(0,1600,0, 1600,Inf,1)) # classify the distances into 0 and
1
# IMARES
```

Appendix E: Benthos suitability models - R code

```
##################################################
# Habitat suitability models based on raster maps
# IMARES
# date: maart 2011
##################################################


##################################################
# Initial settings
##################################################

# clear memory
rm(list=(ls()));

# load packages
library(raster) # for raster/grid algebra
library(sp)
library(lattice)
library(maptools)

# set home dir
direc  <-"N:/Projecten/Building with Nature - Habitat inventory/Model/input_maps_shallow/";
direc2  <-"N:/Projecten/Building with Nature - Habitat inventory/Model/results_benthos/";

##################################################
# Benthic organisms
##################################################
# Reference: Brinkman AG & Bult T. 2002. Geschikte eulitorale gebieden in de Nederlandse
# Waddenzee voor het voorkomen van meerjarige natuurlijke mosselbanken. Alterra Report
# 455. EVA II

# Species: Mussel_seed-drop
# Model: KDD1A2
# glm family used: quasipoisson (log) so transformation needed
# Area: Waddenzee (WAD)

# Variable list:
  # ET_perc      = staat voor emersion time - tijdsduur waarop het wad droogvalt (%)
  # Dis_gul_m     = afstand tot de geulrand (m)

# Create raster maps
ET_perc       <-raster(paste(direc,"ET_proc_wad.asc",sep=""));
Dis_gul_m      <-raster(paste(direc,"DisGR_m_wad.asc",sep=""));

# Suitability function for seed-drop, each variable individually
Sdrop_ET      <-overlay(ET_perc,fun=function(ET_perc) exp(-0.719+2.70e-2*ET_perc-1.50e-
7*I(ET_perc^4)))
Sdrop_Dis_gul <-overlay(Dis_gul_m, fun = function(Dis_gul_m) exp(-0.346 + (1.97e-3 *
Dis_gul_m) - 2.81e-6*I(Dis_gul_m^2)))


# Suitability function for seed-drop, combined variables
Mussel_Sdrop_suit_WAD<-overlay(Sdrop_ET,Sdrop_Dis_gul1,
fun=function(Sdrop_ET,Sdrop_Dis_gul1) Sdrop_ET*Sdrop_Dis_gul1);

#check result
result <- Mussel_Sdrop_suit_WAD
summary(result)
plot(result)
```

```
filename <- "Mussel_seed-drop_wad"

# save result as asc file
  tt<- writeRaster(result, filename= (paste(direc2,filename,"Mussel_seed-
drop_wad.asc",sep="")),format="ascii", overwrite = TRUE)

# save result as figure (for report)
  graphics.off();
  filen <- paste(direc2,filename,".png",sep="")
  png(filen, width=1000, height=1000);
  plot(result)
  dev.off();

##########
# Reference: Brinkman AG & Bult T. 2002. Geschikte eulitorale gebieden in de Nederlandse
# Waddenzee voor het voorkomen van meerjarige natuurlijke mosselbanken. Alterra Report
# 455. EVA II
# Species: Mussel_succession_seed
# Model: RVD1A2
# glm family used: quasipoisson (log) so transformation needed
# Area: Waddenzee (WAD)

# Variable list:
  # ET_perc      = staat voor emision time - tijdsduur waarop het wad droogvalt (%)
  # Dis_gul_m     = afstand tot de geulrand (m)

# Create raster maps
ET_perc       <-raster(paste(direc,"ET_proc_wad.asc",sep=""));
Dis_gul_m      <-raster(paste(direc,"DisGR_m_wad.asc",sep=""));

# Suitability function Seedsuccession, each variable individually
Ssucces_ET      <-overlay(ET_perc,fun=function(ET_perc) exp(-4.694+1.59e-1*ET_perc-6.55e-
7*(ET_perc^4)));
Ssucces_Dis_gul <-overlay(Dis_gul_m,fun=function(Dis_gul_m) exp(-3.194+1.53e-
2*Dis_gul_m-1.83e-5*(Dis_gul_m^2)));


# Suitability function Seedsuccession, combined variables
Mussel_Ssucces_suit_WAD<-overlay(Ssucces_ET,Ssucces_Dis_gul,
fun=function(Ssucces_ET,Ssucces_Dis_gul) Ssucces_ET*Ssucces_Dis_gul);

#check result
result <- Mussel_Ssucces_suit_WAD
summary(result)
plot(result)

filename <- "Mussel_seed_succes_wad"

# save result as asc file
tt<- writeRaster(result, filename=
(paste(direc2,filename,"Mussel_seed_succes_wad.asc",sep="")),format="ascii", overwrite =
TRUE)

# save result as figure (for report)
graphics.off();
filen <- paste(direc2,filename,".png",sep="")
png(filen, width=1000, height=1000);
plot(result)
dev.off();

####################
# Brinkman AG & Hermes Y. 2001. 3.10a Habitatmodel benthische fauna. Effectketen Noordzee:
```

```
# slib, licht, primaire productie, algensoortensamenstelling, zooplankton, benthos, vissen en
# vogels. Alterra Report 02/0029318.

# Species: Bathyporeia elegans (amphipode)
# Model: beschrijft de biomassa in gr adw/m2
# glm family used: quasipoisson (log) so transformation needed
# Area: (midden)Noordzee

# Variable list:
  # Chla_max    = maximale chlorophyl gehalte (ug/l)
  # Depth       = lokale waterdiepte (m)
  # Tim_avr     = (jaar)gemiddelde slibconcentratie in de waterkolom (mg/l)
  # Sed_med_um  = mediane korrelgrootte sediment (um)
  # PrP_max     = primaire productie maximale waarde (gC/m2/dag)
  # Sal_min_ppt = minimale saliniteit (ppt)
  # Sed_slib    = slibgehalte in het sediment,

# Create raster maps
Chla_max    <-raster(paste(direc,"Chla_max.asc",sep=""));
Depth       <-raster(paste(direc,"depthplus.asc",sep=""));
Tim_avr     <-raster(paste(direc,"Tim_avr.asc",sep=""));
Sed_med_um  <-raster(paste(direc,"Sed_med_um.asc",sep=""));
PrP_max     <-raster(paste(direc,"PrP_max.asc",sep=""));
Sal_min_ppt <-raster(paste(direc,"Sal_min_ppt.asc",sep=""));
Sed_slib    <-raster(paste(direc,"Sed_slib.asc",sep=""));

# Suitability function
Bathyporeia_suit<-overlay(Chla_max, Depth, Tim_avr, Sed_med_um, PrP_max, Sal_min_ppt,
Sed_slib,
      fun=function(Chla_max, Depth, Tim_avr, Sed_med_um, PrP_max, Sal_min_ppt, Sed_slib)
      exp(43.43+0.2558*Chla_max-0.00603*(Chla_max^2)-0.00185*(Depth^2)-
0.1325*Tim_avr+0.03245*
      Sed_med_um-0.0000729*(Sed_med_um^2)-0.4893*PrP_max-
3.545*Sal_min_ppt+0.0623*(Sal_min_ppt^2)-0.1851*Sed_slib));

#check result
result <- Bathyporeia_suit
 summary(result)
 plot(result)
 plot(result, zlim=c(0,25))

filename <- "Bathyporeia_gr_adw_m2"
# save result as asc file
  tt<- writeRaster(result, filename= (paste(direc2,filename,".asc",sep="")),format="ascii",
overwrite = TRUE)

# save result as figure (for report)
  graphics.off();
  filen <- paste(direc2,filename,".png",sep="")
  png(filen, width=1000, height=1000);
  plot(result)
  dev.off();


# IMARES
##########
# Brinkman AG & Hermes Y. 2001. 3.10a Habitatmodel benthische fauna. Effectketen Noordzee:
# slib, licht, primaire productie, algensoortensamenstelling, zooplankton, benthos, vissen en
# vogels. Alterra Report 02/0029318.
# IMARES
# Species: Capitella capitata (slangpier)
# Model: beschrijft de biomassa in gr adw/m2
```

```
# glm family used: quasipoisson (log) so transformation needed
# Area: (midden)Noordzee

# Variable list:
  # Chla_max    = maximale chlorophyl gehalte (ug/l)
  # Depth       = lokale waterdiepte (m)
  # Tim_avr     = (jaar)gemiddelde slibconcentratie in de waterkolom (mg/l)
  # PrP_max     = primaire productie maximale waarde (gC/m2/dag)
  # Vel_max_ms  = maximale stroomsnelheid (m/s)
  # Tau_max     = maximale schuifspanning aan de bodem tgv golven (N/m2)

# Create raster maps
Chla_max    <-raster(paste(direc,"Chla_max.asc",sep=""));
Depth       <-raster(paste(direc,"depthplus.asc",sep=""));
Tim_avr     <-raster(paste(direc,"Tim_avr.asc",sep=""));
PrP_max     <-raster(paste(direc,"PrP_max.asc",sep=""));
Vel_max_ms  <-raster(paste(direc,"Vel_max_ms.asc",sep=""));
Tau_max     <-raster(paste(direc,"Tau_max.asc",sep=""));

# Suitability function
Capitella_suit<-overlay(Chla_max, Depth, Tim_avr, PrP_max, Vel_max_ms, Tau_max,
      fun=function(Chla_max, Depth, Tim_avr, PrP_max, Vel_max_ms, Tau_max)
      exp(-2.54+0.475*Chla_max-0.01035*(Chla_max^2)-0.00663*Depth-
0.2068*Tim_avr+0.003288*(Tim_avr^2)-
      1.14*PrP_max+0.0985*(PrP_max^2)-3.451*(Vel_max_ms^2)+0.1856*Tau_max-
0.00814*(Tau_max^2)));

#check result
result <- Capitella_suit
 summary(result)
 plot(result)

filename <- "Capitella_gr_adw_m2"
# save result as asc file
  tt<- writeRaster(result, filename= (paste(direc2,filename,".asc",sep="")),format="ascii",
overwrite = TRUE)

# save result as figure (for report)
  graphics.off();
  filen <- paste(direc2,filename,".png",sep="")
  png(filen, width=1000, height=1000);
  plot(result)
  dev.off();

##########
 # Brinkman AG & Hermes Y. 2001. 3.10a Habitatmodel benthische fauna. Effectketen
#Noordzee:
# slib, licht, primaire productie, algensoortensamenstelling, zooplankton, benthos, vissen en
# vogels. Alterra Report 02/0029318.

# IMARES
# Species: Ensis arcuatus var. directus (mesheft)
# Model: beschrijft de biomassa in gr adw/m2
# glm family used: quasipoisson (log) so transformation needed
# Area: (midden)Noordzee

# Variable list:
  # Chla_max    = maximale chlorophyl gehalte (ug/l)
  # Depth       = lokale waterdiepte (m)
  # Tim_avr     = (jaar)gemiddelde slibconcentratie in de waterkolom (mg/l)
  # Sed_med_um  = mediane korrelgrootte sediment (um)
  # PrP_max     = primaire productie maximale waarde (gC/m2/dag)
```

```
  # Sal_min_ppt = minimale saliniteit (ppt)
  # Sed_slib    = slibgehalte in het sediment, min/max/gemiddeld??? (%)
  # Vel_max_ms  = maximale stroomsnelheid (m/s)
  # Tau_max     = maximale schuifspanning aan de bodem tgv golven (N/m2)

# Create raster maps
Chla_max    <-raster(paste(direc,"Chla_max.asc",sep=""));
Depth       <-raster(paste(direc,"depthplus.asc",sep=""));
Tim_avr     <-raster(paste(direc,"Tim_avr.asc",sep=""));
Sed_med_um  <-raster(paste(direc,"Sed_med_um.asc",sep=""));
PrP_max     <-raster(paste(direc,"PrP_max.asc",sep=""));
Sal_min_ppt <-raster(paste(direc,"Sal_min_ppt.asc",sep=""));
Sed_slib    <-raster(paste(direc,"Sed_slib.asc",sep=""));
Vel_max_ms  <-raster(paste(direc,"Vel_max_ms.asc",sep=""));
Tau_max     <-raster(paste(direc,"Tau_max.asc",sep=""));

# Suitability function
Ensis_suit<-overlay(Chla_max, Depth, Tim_avr, Sed_med_um, PrP_max, Sal_min_ppt,
Sed_slib, Vel_max_ms, Tau_max,
       fun=function(Chla_max, Depth, Tim_avr, Sed_med_um, PrP_max, Sal_min_ppt, Sed_slib,
Vel_max_ms, Tau_max)
       exp(-28.98+0.667*Chla_max-0.0162*(Chla_max^2)-0.207*Depth-
0.0837*Tim_avr+0.0414*Sed_med_um-9.08e-5*(Sed_med_um^2)-
       0.0522*(PrP_max^2)+2.517*Sal_min_ppt-0.0543*(Sal_min_ppt^2)+1.386*Sed_slib-
0.2043*(Sed_slib^2)-5.07*(Vel_max_ms^2)-0.003795*(Tau_max^2)));

#check result
result <- Ensis_suit
 summary(result)
 plot(result)

filename <- "Ensis_gr_adw_m2"
# save result as asc file
  tt<- writeRaster(result, filename= (paste(direc2,filename,".asc",sep="")),format="ascii",
overwrite = TRUE)

# save result as figure (for report)
  graphics.off();
  filen <- paste(direc2,filename,".png",sep="")
  png(filen, width=1000, height=1000);
  plot(result)
  dev.off();


##########
# Brinkman AG & Hermes Y. 2001. 3.10a Habitatmodel benthische fauna. Effectketen Noordzee:
# slib, licht, primaire productie, algensoortensamenstelling, zooplankton, benthos, vissen en
# vogels. Alterra Report 02/0029318.

#IMARES
# Species: Macoma balthica (nonnetje)
# Model: beschrijft de biomassa in gr adw/m2
# glm family used: quasipoisson (log) so transformation needed
# Area: (midden)Noordzee

# Variable list:
  # Chla_max    = maximale chlorophyl gehalte (ug/l)
  # Depth       = lokale waterdiepte (m)
  # Tim_avr     = (jaar)gemiddelde slibconcentratie in de waterkolom (mg/l)
  # Sed_med_um  = mediane korrelgrootte sediment (um)
  # PrP_max     = primaire productie maximale waarde (gC/m2/dag)
  # Sal_min_ppt = minimale saliniteit (ppt)
```

```
  # Sed_slib     = slibgehalte in het sediment, min/max/gemiddeld??? (%)
  # Vel_max_ms  = maximale stroomsnelheid (m/s)
  # Tau_max      = maximale schuifspanning aan de bodem tgv golven (N/m2)

# Create raster maps
Chla_max    <-raster(paste(direc,"Chla_max.asc",sep=""));
Depth       <-raster(paste(direc,"depthplus.asc",sep=""));
Tim_avr     <-raster(paste(direc,"Tim_avr.asc",sep=""));
Sed_med_um  <-raster(paste(direc,"Sed_med_um.asc",sep=""));
PrP_max     <-raster(paste(direc,"PrP_max.asc",sep=""));
Sal_min_ppt <-raster(paste(direc,"Sal_min_ppt.asc",sep=""));
Sed_slib    <-raster(paste(direc,"Sed_slib.asc",sep=""));
Vel_max_ms  <-raster(paste(direc,"Vel_max_ms.asc",sep=""));
Tau_max     <-raster(paste(direc,"Tau_max.asc",sep=""));

# Suitability function
Macoma_suit<-overlay(Chla_max, Depth, Tim_avr, Sed_med_um, PrP_max, Sal_min_ppt,
Sed_slib, Vel_max_ms, Tau_max,
      fun=function(Chla_max, Depth, Tim_avr, Sed_med_um, PrP_max, Sal_min_ppt, Sed_slib,
Vel_max_ms, Tau_max)
      exp(-24.11-0.4063*Chla_max+0.01514*(Chla_max^2)+0.6293*Depth-
0.02554*(Depth^2)+0.1383*Tim_avr+0.001731*(Tim_avr^2)
      -0.00608*Sed_med_um+0.782*PrP_max-
0.1622*(PrP_max^2)+0.3135*Sal_min_ppt+0.1003*Sed_slib+36.89*Vel_max_ms-
29.74*(Vel_max_ms^2)+0.2378*Tau_max-0.00352*(Tau_max^2)));

#check result
result <- Macoma_suit
 summary(result)
 plot(result, zlim=c(0,100))

filename <- "Macoma_gr_adw_m2"
# save result as asc file
  tt<- writeRaster(result, filename= (paste(direc2,filename,".asc",sep="")),format="ascii",
overwrite = TRUE)

# save result as figure (for report)
  graphics.off();
  filen <- paste(direc2,filename,".png",sep="")
  png(filen, width=1000, height=1000);
  plot(result)
  dev.off();


##########
# Brinkman AG & Hermes Y. 2001. 3.10a Habitatmodel benthische fauna. Effectketen Noordzee:
# slib, licht, primaire productie, algensoortensamenstelling, zooplankton, benthos, vissen en
# vogels. Alterra Report 02/0029318.
# IMARES
# Species: Nephtys cirrosa (borstelworm)
# Model: beschrijft de biomassa in gr adw/m2
# glm family used: quasipoisson (log) so transformation needed
# Area: (midden)Noordzee

# Variable list:
  # Depth        = lokale waterdiepte (m)
  # Tim_avr      = (jaar)gemiddelde slibconcentratie in de waterkolom (mg/l)
  # Sed_med_um  = mediane korrelgrootte sediment (um)
  # PrP_max      = primaire productie maximale waarde (gC/m2/dag)
  # Sal_min_ppt = minimale saliniteit (ppt)
  # Sed_slib     = slibgehalte in het sediment, min/max/gemiddeld??? (%)
  # Vel_max_ms  = maximale stroomsnelheid (m/s)
```

```
# Create raster maps
Depth       <-raster(paste(direc,"depthplus.asc",sep=""));
Tim_avr     <-raster(paste(direc,"Tim_avr.asc",sep=""));
Sed_med_um  <-raster(paste(direc,"Sed_med_um.asc",sep=""));
PrP_max     <-raster(paste(direc,"PrP_max.asc",sep=""));
Sal_min_ppt <-raster(paste(direc,"Sal_min_ppt.asc",sep=""));
Sed_slib    <-raster(paste(direc,"Sed_slib.asc",sep=""));
Vel_max_ms  <-raster(paste(direc,"Vel_max_ms.asc",sep=""));

# Suitability function
Nephtys_cir_suit<-overlay(Depth, Tim_avr, Sed_med_um, PrP_max, Sal_min_ppt, Sed_slib,
Vel_max_ms,
        fun=function(Depth, Tim_avr, Sed_med_um, PrP_max, Sal_min_ppt, Sed_slib,
Vel_max_ms)
        exp(-31.12-0.03682*Depth-0.082*Tim_avr+0.001438*(Tim_avr^2)-2.23e-
6*(Sed_med_um^2)
        -0.02176*(PrP_max^2)+1.922*Sal_min_ppt-0.03328*(Sal_min_ppt^2)-
0.0827*Sed_slib+0.00332*(Sed_slib^2)+5.415*Vel_max_ms));

#check result
result <- Nephtys_cir_suit
 summary(result)
 plot(result)
 plot(result, zlim=c(0,10))

filename <- "Nephtys_cir_gr_adw_m2"
# save result as asc file
  tt<- writeRaster(result, filename= (paste(direc2,filename,".asc",sep="")),format="ascii",
overwrite = TRUE)

# save result as figure (for report) SG: oorspronkelijke plot
  graphics.off();
  filen <- paste(direc2,filename,".png",sep="")
  png(filen, width=1000, height=1000);
  plot(result)
  dev.off();


##########
# Brinkman AG & Hermes Y. 2001. 3.10a Habitatmodel benthische fauna. Effectketen Noordzee:
# slib, licht, primaire productie, algensoortensamenstelling, zooplankton, benthos, vissen en
# vogels. Alterra Report 02/0029318.
# IMARES
# Species: Nephtys hombergii (zandzager (borstelworm))
# Model: beschrijft de biomassa in gr adw/m2
# glm family used: quasipoisson (log) so transformation needed
# Area: (midden)Noordzee en Waddenzee

# Variable list:
  # Depth       = lokale waterdiepte (m)
  # Sed_med_um  = mediane korrelgrootte sediment (um)
  # Sal_min_ppt = minimale saliniteit (ppt)
  # Sed_slib    = slibgehalte in het sediment, min/max/gemiddeld??? (%)
  # Vel_max_ms  = maximale stroomsnelheid (m/s)
  # Tau_max     = maximale schuifspanning aan de bodem tgv golven (N/m2)

# Create raster maps
Depth       <-raster(paste(direc,"depthplus.asc",sep=""));
Sed_med_um  <-raster(paste(direc,"Sed_med_um.asc",sep=""));
Sal_min_ppt <-raster(paste(direc,"Sal_min_ppt.asc",sep=""));
Sed_slib    <-raster(paste(direc,"Sed_slib.asc",sep=""));
```

```
Vel_max_ms  <-raster(paste(direc,"Vel_max_ms.asc",sep=""));
Tau_max     <-raster(paste(direc,"Tau_max.asc",sep=""));

# Suitability function
Nepthys_hom_suit<-overlay(Depth, Sed_med_um, Sal_min_ppt, Sed_slib, Vel_max_ms,
Tau_max,
        fun=function(Depth, Sed_med_um, Sal_min_ppt, Sed_slib, Vel_max_ms, Tau_max)
        exp(-19.01+0.204*Depth-0.002909*(Depth^2)-
0.0077*Sed_med_um+1.117*Sal_min_ppt-0.02129*(Sal_min_ppt^2)
        -0.000749*(Sed_slib^2)+9.31*Vel_max_ms-8.2*(Vel_max_ms^2)+0.2176*Tau_max-
0.00316*(Tau_max^2)));

#check result
result <- Nepthys_hom_suit
 summary(result)
 plot(result )

filename <- "Nepthys_hom_suit_gr_adw_m2"
# save result as asc file
  tt<- writeRaster(result, filename= (paste(direc2,filename,".asc",sep="")),format="ascii",
overwrite = TRUE)

# save result as figure (for report)
  graphics.off();
  filen <- paste(direc2,filename,".png",sep="")
  png(filen, width=1000, height=1000);
  plot(result)
  dev.off();


##########
# Brinkman AG & Hermes Y. 2001. 3.10a Habitatmodel benthische fauna. Effectketen Noordzee:
# slib, licht, primaire productie, algensoortensamenstelling, zooplankton, benthos, vissen en
# vogels. Alterra Report 02/0029318.
# IMARES
# Species: Spisula subtruncata (halfgeknotte strandschelp)
# Model: beschrijft de biomassa in gr adw/m2
# glm family used: quasipoisson (log) so transformation needed
# Area: (midden)Noordzee en Waddenzee

# Variable list:
  # Chla_max    = maximale chlorophyl gehalte (ug/l)
  # Depth       = lokale waterdiepte (m)
  # Tim_avr     = (jaar)gemiddelde slibconcentratie in de waterkolom (mg/l)
  # Sed_med_um  = mediane korrelgrootte sediment (um)
  # PrP_max     = primaire productie maximale waarde (gC/m2/dag)
  # Sal_min_ppt = minimale saliniteit (ppt)
  # Sed_slib    = slibgehalte in het sediment, min/max/gemiddeld??? (%)
  # Vel_max_ms  = maximale stroomsnelheid (m/s)
  # Tau_max     = maximale schuifspanning aan de bodem tgv golven (N/m2)

# Create raster maps
Chla_max    <-raster(paste(direc,"Chla_max.asc",sep=""));
Depth       <-raster(paste(direc,"depthplus.asc",sep=""));
Tim_avr     <-raster(paste(direc,"Tim_avr.asc",sep=""));
Sed_med_um  <-raster(paste(direc,"Sed_med_um.asc",sep=""));
PrP_max     <-raster(paste(direc,"PrP_max.asc",sep=""));
Sal_min_ppt <-raster(paste(direc,"Sal_min_ppt.asc",sep=""));
Sed_slib    <-raster(paste(direc,"Sed_slib.asc",sep=""));
Vel_max_ms  <-raster(paste(direc,"Vel_max_ms.asc",sep=""));
Tau_max     <-raster(paste(direc,"Tau_max.asc",sep=""));
```

```
# Suitability function
Spisula_suit<-overlay(Chla_max, Depth, Tim_avr, Sed_med_um, PrP_max, Sal_min_ppt,
Sed_slib, Vel_max_ms, Tau_max,
	fun=function(Chla_max, Depth, Tim_avr, Sed_med_um, PrP_max, Sal_min_ppt, Sed_slib,
Vel_max_ms, Tau_max)
	exp(-35.9+0.589*Chla_max-0.03209*(Chla_max^2)+1.129*Depth-0.03198*(Depth^2)-
0.0495*Tim_avr
	-0.01693*Sed_med_um+3.05e-
5*(Sed_med_um^2)+0.879*PrP_max+2.825*Sal_min_ppt-0.0606*(Sal_min_ppt^2)+
	0.822*Sed_slib-0.1854*(Sed_slib^2)-10.649*(Vel_max_ms^2)+0.394*Tau_max-
0.01326*(Tau_max^2)));

#check result
result <- Spisula_suit
 summary(result)
 plot(result)
 plot(result, zlim=c(0,0.5))

filename <- "Spisula_suit_gr_adw_m2"
# save result as asc file
  tt<- writeRaster(result, filename= (paste(direc2,filename,".asc",sep="")),format="ascii",
overwrite = TRUE)

# save result as figure (for report)
  graphics.off();
  filen <- paste(direc2,filename,".png",sep="")
  png(filen, width=1000, height=1000);
  plot(result)
  dev.off();



###################
#Steenbergen J & Meesters E. 2006. Habitatmodellen in het beheer: zijn state-of-the-art
# modellen voor kokkels in de Westerschelde bruikbaar voor beheer en beleidsbesluiten?
# IMARES Report C091/06.
#IMARES
# Species: Cerastoderma edule (kokkel)
# Model: beschrijft (kokkels/m2); beste resultaat nav presence-absence voorspelling
# glm family used: quasipoisson (log) so transformation needed
# Area: Westerschelde (WS)

# Variable list:
  # Sal_avr_psu   = minimale saliniteit (psu)
  # Sed_med_phi   = mediane korrelgrootte sediment (phi)

# Create raster maps
Sal_avr_psu    <-raster(paste(direc,"Sal_avg_ppt.asc",sep=""));
Sed_med_phi    <-raster(paste(direc,"Sed_med_phi.asc",sep=""));

# Suitability function
Cerastoderma_suit_WS<-overlay(Sal_avr_psu, Sed_med_phi,
	fun=function(Sal_avr_psu, Sed_med_phi)
	exp(-96.8913+5.315126*Sal_avr_psu-
0.09935*(Sal_avr_psu^2)+18.36358*Sed_med_phi-3.00214*(Sed_med_phi^2)));

#check result
result <- Cerastoderma_suit_WS
 summary(result)
 plot(result)

filename <- "Cerastoderma_WS_KOA"
```

```
# save result as asc file
  tt<- writeRaster(result, filename= (paste(direc2,filename,".asc",sep="")),format="ascii",
overwrite = TRUE)

# save result as figure (for report)
  graphics.off();
  filen <- paste(direc2,filename,".png",sep="")
  png(filen, width=1000, height=1000);
  plot(result)
  dev.off();

####################
# Kater BJ, Brinkman AG, Baars JMDD & Aarts G. 2004. Kokkelhabitatkaarten voor de
# Oosterschelde en Waddenzee. Eindrapport EVA II deelprojekt H3. IMARES Report C060/03.
# Kater BJ, Geurts van Kessel AJM & Baars JJMD. 2006. Distribution of cockles Cerastoderma
#edule in the Eastern Scheldt: habitat mapping with abiotic variables. Marine Ecology Progress
# Series 318: 221-227.
# IMARES
# Species: Cerastoderma edule (kokkel)
# Model: beschrijft de kans op aanwezigheid van plekken met >50 kokkels per m2
# glm family used: logistisch quasipoisson (log) so transformation needed
# Area: Oosterschelde (OS)

# NB DOOR ONTBREKEN KAARTMATERIAAL NOG NIET GECONTROLEERD

# Variable list:
  # ET_%        = staat voor emision time - tijd waarop het wad droogvalt (%)
  # Vel_max_cms = maximale stroomsnelheid bij eb (cm/s)

# Create raster maps
ET_proc      <-raster(paste(direc,"ET_proc_wad.asc",sep=""));      #SG: Kaart is nog niet
beschikbaar voor OS. Wordt nagevraagd bij Elze (12-3-2012)
Vel_max_cms  <-raster(paste(direc,"Vel_max_cms.asc",sep=""));       #SG: Wellicht komt er
een betere kaart voor OS specifiek.

# Suitability function
Cerastoderma_suit_OS<-overlay(Vel_max_cms, ET_proc,
        fun=function(Vel_max_cms, ET_proc)
        (exp(-6.8+0.19*Vel_max_cms-0.0036*(Vel_max_cms^2)+0.19*ET_proc-
0.0018*(ET_proc^2))/
        (1+exp(-6.8+0.19*Vel_max_cms-0.0036*(Vel_max_cms^2)+0.19*ET_proc-
0.0018*(ET_proc^2)))));


####################
# Tulp I, van Damme C, Quirijns F, Binnendijk E & Borges L. 2006. Vis in de Voordelta:
# nulmeting in het kader van de aanleg van de tweede Maasvlakte. IMARES Report C081/06.
# IMARES
# Species: Crangon crangon (garnaal)
# Model: beschrijft de dichtheid in n/ha
# glm family used: Lineaire regressiemodellen op getransformeerde data (ln voor garnaal)
## Area: Zeeuwse kust (ZK)
## period: Najaar

# Variable list:
  # Sal_avg  = Zoutgehalte (psu), gemiddelde
  # Secci_m    = doorzicht in meter

# Create raster maps
Sal_avg_ppt  <-raster(paste(direc,"Sal_avg_ppt.asc",sep=""));
Secci_m      <-raster(paste(direc,"Secchi_avg.asc",sep=""));
```

```
## period: Voorjaar
# Suitability function
Crangon_suit_ZK_vj<-overlay(Sal_avg_ppt, Secci_m,
    fun=function(Sal_avg_ppt, Secci_m)
    exp( (11.67-1.1) - 0.12 * Sal_avg_ppt - 0.84*Secci_m) );

#check result
result <- Crangon_suit_ZK_vj
summary(result)
plot(result)

filename <- "Crangon_ZK_vj_nha"
# save result as asc file
tt<- writeRaster(result, filename= (paste(direc2,filename,".asc",sep="")),format="ascii",
overwrite = TRUE)

# save result as figure (for report)
graphics.off();
filen <- paste(direc2,filename,".png",sep="")
png(filen, width=1000, height=1000);
plot(result)
dev.off();

## period: najaar
# Suitability function
Crangon_suit_ZK_nj<-overlay(Sal_avg_ppt, Secci_m, fun=function(Sal_avg_ppt, Secci_m)
  exp( (11.67) - 0.12 * Sal_avg_ppt - 0.84*Secci_m));

#check result
result <- Crangon_suit_ZK_nj
summary(result)
plot(result)

filename <- "Crangon_ZK_nj_nha"
# save result as asc file
tt<- writeRaster(result, filename= (paste(direc2,filename,".asc",sep="")),format="ascii",
overwrite = TRUE)

# save result as figure (for report)
graphics.off();
filen <- paste(direc2,filename,".png",sep="")
png(filen, width=1000, height=1000);
plot(result)
dev.off();
# IMARES
```

Appendix F: Habitattypes suitability models - R code

```
########################################################
# Habitat suitability models based on raster maps
# IMARES
# date:5-3-2012
########################################################


########################################################
# Initial settings
########################################################

# clear memory
rm(list=(ls()));

# load packages
library(raster) # for raster/grid algebra
library(sp)
library(lattice)
library(maptools)
library(rgdal)

# set home dir
direc  <-"N:/Projecten/Building with Nature - Habitat inventory/Model/input_maps_shallow/";
direc2  <-"N:/Projecten/Building with Nature - Habitat inventory/Model/results_habitattype/";



########################################################
# Habitat types
########################################################
# reference: Jak et al. 2010. Abiotische kenmerken zoute
# habitattypen Natura 2000. IMARES Rapport C141/10 IMARES

# H1110_A Permanent overstroomde zandbanken (getijdengebied)
# H1110_B Permanent overstroomde zandbanken (Noordzee-kustzone)
# H1110_C Permanent overstroomde zandbanken (Doggersbank)
# H1130 Estuaria
# H1140_A Slik- en zandplaten (getijdengebied)
# H1140_B Slik- en zandplaten (Noordzee-kustzone)
# H1160 Grote baaien
# H1170 Riffen van open zee

# variable list:
# eutrophication level (voedselrijkdom), DIN (winter average (dec-jan-feb)in (μmol/L) or
(μgN/L) or classes thereof.
# salinity, annual average (mg/l) or classes thereof
# acidity (pH), or classes thereof: Zuurgraad is niet onderscheidend voor habitatclassificering en
wordt daarom niet in de functie opgenomen
# current velocity(m/s) daily average   not used for classification in Jak et al. 2010.
# orbitaalspeed (m/s) daily average     not used for classification in Jak et al. 2010.
# breaking waves (yes-no)               not used for classification in Jak et al. 2010.
# shearstress (N/m2)
# secchi depth (m)(water clarity)

#######
# suitability functions per habitat type
#######


#####
```

```
# H1110_A Permanent overstroomde zandbanken (getijdengebied):
# Waddenzee > niet aanwezig op huidige kaart!
#####

# Create raster maps
#din_mol        <- raster(paste(direc,"din_mol",sep=""));
#or
din_gram       <- raster(paste(direc,"Din_ugNl.asc",sep=""));

sal            <- raster(paste(direc,"Sal_avg_ppt.asc",sep=""));
secchi          <- raster(paste(direc,"Secchi_avg.asc",sep=""));
shear           <- raster(paste(direc,"Tau_med.asc",sep=""));

## eutrophication level
# in case of DIN (µmol/L)
# eutrophy_H1110A <- reclass(din_mol, c(-Inf,6.5,0, 6.5,10,1, 10,15,0.5, 15,Inf,0))
# in case of DIN (µgN/L)
 eutrophy_H1110A <- reclass(din_gram, c(-Inf,70,0, 70,140,1, 140,210,0.5, 210,Inf,))


## salinity
 sal_H1110A       <- reclass(sal, c(-Inf,1.8,0, 1.8,5,0.5, 5,Inf,1))

## secchi depth
 secchi_H1110A     <- reclass(secchi, c(0,4,1, 4,Inf,0))

## shearstress
 shear_H1110A      <- reclass(shear, c(0,10,1, 10,30,0.5))

## final suitability is minimal suitability value of all variables combined.
H1110_A_final_hsi <- min(eutrophy_H1110A,sal_H1110A,secchi_H1110A,shear_H1110A)

 #check result
result <- H1110_A_final_hsi
 summary(result)
 plot(result)

 filename <- "H1110_A_final_hsi"
# save result as asc file

  tt<- writeRaster(result, filename= (paste(direc2,filename,".asc",sep="")),format="ascii",
overwrite = FALSE)
# save result as figure (for report)
  graphics.off();
  filen <- paste(direc2,filename,".png",sep="")
  png(filen, width=1000, height=1000);
  plot(result)
  dev.off();


      #####
# H1110_B Permanent overstroomde zandbanken (Noordzee-kustzone):
# Noordzeekustzone (7), Voordelta(113 ) en Westerschelde & Saeftinghe (122).
#####

# Create raster maps
#din_mol        <- raster(paste(direc,"din_mol",sep=""));
din_gram       <- raster(paste(direc,"Din_ugNl.asc",sep=""));
sal            <- raster(paste(direc,"sal_avg.ppt.asc",sep=""));
secchi          <- raster(paste(direc,"secchi_avg_ppt.asc",sep=""));
shear           <- raster(paste(direc,"Tau_med.asc",sep=""));
```

```
## eutrophication level
# in case of DIN (µmol/L)
# eutrophy_H1110B <- reclass(din_mol, c(-Inf,15,0, 15,30,1, 30,Inf,0))
# in case of DIN (µgN/L)
 eutrophy_H1110B <- reclass(din_gram, c(-Inf,210,0, 210,420,1, 420.1,Inf,0.1))
 # aanpassing: > 420 HSI =0.1. dit is gedaan omdat anders niets wordt aangemerkt,
 # nu met 0.1 is te zien dat de status slecht is.
 # dit omdat het type wel aanwezig is, maar slecht scoort.


## salinity
 sal_H1110B        <- reclass(sal, c(-Inf,1.8,0, 1.8,5,0.5, 5,Inf,1))

## secchi depth
 secchi_H1110B     <- reclass(secchi, c(0,0.2,0, 0.2,4,1, 4,Inf,0))

## shearstress
 shear_H1110B      <- reclass(shear, c(0,10,1, 10,30,0.5))

## final suitability is minimal suitability value of all variables combined.
H1110_B_final_hsi <- min(eutrophy_H1110B,sal_H1110B,secchi_H1110B,shear_H1110B)

#check result
result <- H1110_B_final_hsi
 summary(result)
 plot(result)

 filename <- "H1110_B_final_hsi"
# save result as asc file

  tt<- writeRaster(result, filename= (paste(direc2,filename,".asc",sep="")),format="ascii",
overwrite = FALSE)
# save result as figure (for report)
  graphics.off();
  filen <- paste(direc2,filename,".png",sep="")
  png(filen, width=1000, height=1000);
  plot(result)
  dev.off();


     #####
# H1110_C Permanent overstroomde zandbanken (Doggersbank):
# niet op huidige uitsnede van de kaart
#####

# Create raster maps
#din_mol        <- raster(paste(direc,"din_mol",sep=""));
din_gram        <- raster(paste(direc,"Din_ugNL.asc",sep=""));
sal             <- raster(paste(direc,"Sal_avg_ppt.asc",sep=""));
secchi          <- raster(paste(direc,"secchi_avg_ppt.asc",sep=""));
shear           <- raster(paste(direc,"Tau_med.asc",sep=""));

## eutrophication level
# in case of DIN (µmol/L)
# eutrophy_H1110C <- reclass(din_mol, c(-Inf,10,0, 10,15,1, 15,30,0.5, 30.1,Inf,0))
# in case of DIN (µgN/L)
 eutrophy_H1110C <- reclass(din_gram, c(-Inf,140,0, 140,210,1, 210,420,0.5, 420.1,Inf,0))

## salinity
 sal_H1110C       <- reclass(sal, c(-Inf,30,0, 30.1,Inf,1))
```

```
## secchi depth
 secchi_H1110C     <- reclass(secchi, c(0,4,0, 4,Inf,1))

## shearstress
 shear_H1110C      <- reclass(shear, c(0,10,1, 10,30,0.5))

## final suitability is minimal suitability value of all variables combined.
H1110_C_final_hsi <- min(eutrophy_H1110C,sal_H1110C,secchi_H1110C,shear_H1110C)

#check result
result <- H1110_C_final_hsi
 summary(result)
 plot(result)

 filename <- "H1110_C_final_hsi"
# save result as asc file

  tt<- writeRaster(result, filename= (paste(direc2,filename,".asc",sep="")),format="ascii",
overwrite = FALSE)
# save result as figure (for report)
  graphics.off();
  filen <- paste(direc2,filename,".png",sep="")
  png(filen, width=1000, height=1000);
  plot(result)
  dev.off();


    #####
# H1130 Estuaria: Westerschelde & Saeftinghe, 1 22) en de Eems- Dollard (Waddenzee, 1 ).

# classificatie van Jak levert hele NL kust op.
# geografische selectie lijkt zinvoller, daarna de status bepalen met onderstaande regels.
#####

# Create raster maps
#din_mol        <- raster(paste(direc,"din_mol",sep=""));
din_gram       <- raster(paste(direc,"Din_ugNL.asc",sep=""));
sal            <- raster(paste(direc,"Sal_avg_ppt.asc",sep=""));
secchi         <- raster(paste(direc,"secchi_avg_ppt",sep=""));
shear          <- raster(paste(direc,"Tau_med.asc",sep=""));

## eutrophication level
# in case of DIN (µmol/L)
# eutrophy_H1130 <- reclass(din_mol, c(-Inf,15,0, 15,30,1, 30.1,Inf,0))
# in case of DIN (µgN/L)
eutrophy_H1130 <- reclass(din_gram, c(-Inf,210,0, 210,420,1, 420.1,Inf,0.1))
 # aanpassing: > 420 HSI =0.1. dit is gedaan omdat anders niets wordt aangemerkt,
  # nu met 0.1 is te zien dat de status slecht is.
  # dit omdat het type wel aanwezig is, maar slecht scoort.
## salinity
 sal_H1130       <- reclass(sal, c(0,Inf,1))

## secchi depth
 secchi_H1130     <- reclass(secchi, c(0,4,1, 4,Inf,0))

## shearstress
 shear_H1130      <- reclass(shear, c(0,10,1, 10,30,0.5))

## final suitability is minimal suitability value of all variables combined.
H1130_final_hsi <- min(eutrophy_H1130,sal_H1130,secchi_H1130,shear_H1130)

#check result
```

```
result <- H1130_final_hsi
 summary(result)
 plot(result)

 filename <- "H1130_final_hsi"
# save result as asc file

  tt<- writeRaster(result, filename= (paste(direc2,filename,".asc",sep="")),format="ascii",
overwrite = FALSE)
# save result as figure (for report)
  graphics.off();
  filen <- paste(direc2,filename,".png",sep="")
  png(filen, width=1000, height=1000);
  plot(result)
  dev.off();

    #####
# H1140_A Slik- en zandplaten (getijdengebied):Waddenzee (1) is dit subtype
#aangewezen voor de Voordelta (113). Verder
#komt het subtype voor als onderdeel van habitattypen
#estuaria (H1130) en grote baaien (H1160) in
#Westerschelde & Saeftinghe (122) en Oosterschelde
#(118). Alleen voor de Waddenzee (1) wordt
#gestreefd naar verbetering kwaliteit.
#####
# met de huidige indeling is de gehele zone te eutroof en niet onderscheidend voor de aan
# gegeven lokaties die hier onder moeten vallen. Beter lijkt een indeling op locatie
# en het toevoegen van bijvoorbeeld diepte of droogvalduur.


# Create raster maps
#din_mol         <- raster(paste(direc,"din_mol",sep=""));
din_gram        <- raster(paste(direc,"Din_ugNL.asc",sep=""));
sal             <- raster(paste(direc,"Sal_avg_ppt.asc",sep=""));
secchi          <- raster(paste(direc,"secchi_avg_ppt.asc",sep=""));
shear           <- raster(paste(direc,"Tau_med.asc",sep=""));

## eutrophication level
# in case of DIN (µmol/L)
#eutrophy_H1140_A <- reclass(din_mol, c(-Inf,6.5,0, 6.5,10,1, 10,15,0.5, 15,Inf,0))
# in case of DIN (µgN/L)
eutrophy_H1140_A <- reclass(din_gram, c(-Inf,70,0, 70,140,1, 140,210,0.5, 210,Inf,0))

## salinity
 sal_H1140_A      <- reclass(sal, c(-Inf,1.8,0, 1.8,5,0.5, 5,Inf,1))

## secchi depth
 secchi_H1140_A     <- reclass(secchi, c(0,4,1, 4,Inf,0))

## shearstress
 shear_H1140_A      <- reclass(shear, c(0,10,1, 10,30,0.5))

## final suitability is minimal suitability value of all variables combined.
H1140_A_final_hsi <- min(eutrophy_H1140_A,sal_H1140_A,secchi_H1140_A,shear_H1140_A)

#check result
result <- H1140_A_final_hsi
 summary(result)
 plot(result)

 filename <- "H1140_A_final_hsi"
# save result as asc file
```

```
 tt<- writeRaster(result, filename= (paste(direc2,filename,".asc",sep="")),format="ascii",
overwrite = FALSE)
# save result as figure (for report)
 graphics.off();
 filen <- paste(direc2,filename,".png",sep="")
 png(filen, width=1000, height=1000);
 plot(result)
 dev.off();


  #####
# H1140_B Slik- en zandplaten (Noordzee-kustzone):Noordzeekustzone (7) en Voordelta (113).
#####
# zelfde probleem als bij subtype A. Diepte of droogvalduur lijken noodzakelijk om tot
# de juiste selectie te komen. Anders is er geen verschil met H1110 B.

# Create raster maps
#din_mol         <- raster(paste(direc,"din_mol",sep=""));
din_gram        <- raster(paste(direc,"Din_ugNL.asc",sep=""));
sal             <- raster(paste(direc,"Sal_avg_ppt.asc",sep=""));
secchi          <- raster(paste(direc,"secchi_avg_ppt.asc",sep=""));
shear           <- raster(paste(direc,"Tau_med.asc",sep=""));

## eutrophication level
# in case of DIN (µmol/L)
# eutrophy_H1140_B <- reclass(din_mol, c(-Inf,15,0, 15,30,1, 30.1,Inf,0))
# in case of DIN (µgN/L)
 eutrophy_H1140_B <- reclass(din_gram, c(-Inf,210,0, 210,420,1, 420.1,Inf,0))

## salinity
 sal_H1140_B      <- reclass(sal, c(-Inf,1.8,0, 1.8,5,0.5, 5,Inf,1))

## secchi depth
 secchi_H1140_B    <- reclass(secchi, c(0,0.2,0, 0.2,4,1, 4,Inf,0))

## shearstress
 shear_H1140_B     <- reclass(shear, c(0,10,1, 10,30,0.5))

## final suitability is minimal suitability value of all variables combined.
H1140_B_final_hsi <- min(eutrophy_H1140_B,sal_H1140_B,secchi_H1140_B,shear_H1140_B)

#check result
result <- H1140_B_final_hsi
 summary(result)
 plot(result)

 filename <- "H1140_B_final_hsi"
# save result as asc file

 tt<- writeRaster(result, filename= (paste(direc2,filename,".asc",sep="")),format="ascii",
overwrite = FALSE)
# save result as figure (for report)
 graphics.off();
 filen <- paste(direc2,filename,".png",sep="")
 png(filen, width=1000, height=1000);
 plot(result)
 dev.off();


    #####
# H1160  Grote baaien: Oosterschelde(118)
```

```
#####
# grote overlap in optima van variabelen met 1170(riffen op zee).
# geografische selectie noodzakelijk voor voldoende onderscheid.
# diepte wellicht ook goed toevoeging

# Create raster maps
#din_mol         <- raster(paste(direc,"din_mol",sep=""));
din_gram        <- raster(paste(direc,"Din_ugNL.asc",sep=""));
sal             <- raster(paste(direc,"Sal_avg_ppt.asc",sep=""));
secchi          <- raster(paste(direc,"secchi_avg_ppt.asc",sep=""));
shear           <- raster(paste(direc,"Tau_med.asc",sep=""));

## eutrophication level
# in case of DIN (µmol/L)
# eutrophy_H1160 <- reclass(din_mol, c(-Inf,15,0, 15,30,1, 30.1,Inf,0))
# in case of DIN (µgN/L)
 eutrophy_H1160 <- reclass(din_gram, c(-Inf,210,0, 210,420,1, 420.1,Inf,0))

## salinity
 sal_H1160      <- reclass(sal, c(-Inf,5,0, 5,18,0.5, 18,Inf,1))

## secchi depth
 secchi_H1160     <- reclass(secchi, c(0,0.19,0, 0.2,10,1, 10.1,Inf,0))

## shearstress
 shear_H1160     <- reclass(shear, c(0,1.49,1, 1.5,10,0.5, 10,30,0))

## final suitability is minimal suitability value of all variables combined.
H1160_final_hsi <- min(eutrophy_H1160,sal_H1160,secchi_H1160,shear_H1160)

#check result
result <- H1160_final_hsi
 summary(result)
 plot(result)

 filename <- "H1160_final_hsi"
# save result as asc file

  tt<- writeRaster(result, filename= (paste(direc2,filename,".asc",sep="")),format="ascii",
overwrite = FALSE)
# save result as figure (for report)
  graphics.off();
  filen <- paste(direc2,filename,".png",sep="")
  png(filen, width=1000, height=1000);
  plot(result)
  dev.off();


        #####
# H1170  Riffen van open zee: Klaverbank
#niet aanwezig in ondiepe kust zone van <10m diep.
#####

# Create raster maps
#din_mol         <- raster(paste(direc,"din_mol",sep=""));
din_gram        <- raster(paste(direc,"Din_ugNL.asc",sep=""));
sal             <- raster(paste(direc,"Sal_avg_ppt.asc",sep=""));
secchi          <- raster(paste(direc,"secchi_avg_ppt.asc",sep=""));
shear           <- raster(paste(direc,"Tau_med.asc",sep=""));

## eutrophication level
# in case of DIN (µmol/L)
```

```
# eutrophy_H1170 <- reclass(din_mol, c(-Inf,10,0, 10,15,1, 15,30,0.5, 30.1,Inf,0))
# in case of DIN (µgN/L)
 eutrophy_H1170 <- reclass(din_gram, c(-Inf,140,0, 140,210,1, 210,420,0.5, 420.1,Inf,0))

## salinity
 sal_H1170      <- reclass(sal, c(-Inf,18,0, 18,Inf,1))

## secchi depth
 secchi_H1170     <- reclass(secchi, c(0,4,0, 4,Inf,1))

## shearstress
 shear_H1170     <- reclass(shear, c(0,1.49,1, 1.5,10,0.5, 10,30,0))

## final suitability is minimal suitability value of all variables combined.
H1170_final_hsi <- min(eutrophy_H1170,sal_H1170,secchi_H1170,shear_H1170)

#check result
result <- H1170_final_hsi
 summary(result)
 plot(result)

 filename <- "H1170_final_hsi"
# save result as asc file

  tt<- writeRaster(result, filename= (paste(direc2,filename,".asc",sep="")),format="ascii",
overwrite = FALSE)
# save result as figure (for report)
  graphics.off();
  filen <- paste(direc2,filename,".png",sep="")
  png(filen, width=1000, height=1000);
  plot(result)
  dev.off();
# IMARES
```