Impacts of Human Activities

User limits or natural limits: can we set limits to human use, based on a natural functioning of the Wadden Sea?

M.J. Baptist (martin.baptist@wur.nl)[1,3], N. Dankers[1], C.J. Bastmeijer[2], A.G. Brinkman[1], J.E. Tamis[1], R. Jongbloed[1], F.E. Fey[1], W.E. van Duin[1], C.J. Smit[1], H.J. Lindeboom[1]
[1]Wageningen IMARES, [2]Faculty of Law, Tilburg University, [3]Corresponding author.

Abstract

In The Netherlands, a new policy framework for limiting human use in marine protected areas was proposed in 2004. The framework consists of a system of 'natural limits' for which scientific consensus exist that as long as these limits are not exceeded, natural processes in the Wadden Sea will not be significantly influenced. This proposal produced much discussion as well as confusion concerning definitions. Should we speak of 'natural limits' or rather 'user limits'? Are the limits set by the natural processes of the Wadden Sea, or rather by policy makers? And, last but not least, how do we quantify these limits in the light of the complexity and dynamics of the Wadden Sea ecosystem, and will they stand in legal procedures? In this study we evaluated the feasibility of the proposed framework from an ecological and juridical perspective. We made a distinction between two types of limits, those set by law and policy, such as the EU Habitats and Birds Directives or the trilateral Eco-targets, and those set by ecological knowledge, such as carrying capacity and minimal viable population size. We studied available knowledge and defined limits based on natural processes for salt marshes, mussel beds, bird populations and habitat type 1140 (intertidal areas). Next, we formulated a step-by-step approach for setting limits to human use based on clear definitions for nature types. We studied whether this could lead to spatio-temporally defined user limits agreed upon by policy. We concluded that since the Wadden Sea is highly dynamic, any system of user limits should be made flexible and would require continuous monitoring and a system of adaptive management. We further concluded that a system of generic user limits, valid for all types of activities in all of the Wadden Sea is not feasible. Each proposed plan or activity needs a location specific assessment for which local and overall cumulative effects need to be assessed and weighted; however, scientifically well supported natural limits could substantially support the implementation of the legal system and the final go or no-go decision.

1. Introduction

In 2004, the Dutch Advisory Committee on Wadden Sea Policy suggested a new policy framework to set limits to human use in the Wadden Sea (Meijer *et al*., 2004). The framework consists of a system of 'natural limits' for which scientific consensus exists that as long as these limits are not exceeded, natural processes in the Wadden Sea would not be significantly influenced. The framework sets limits to human use, based on the premise that in the Wadden Sea natural features stand above human uses. The Committee suggested setting up a generic set of natural limits, valid for the entire Wadden Sea and for all types of activities. Once the limits are established, making the appropriate assessment (according to the EU Habitats Directive) of a new plan or project in the Wadden Sea should be easier.

In 2007, the Dutch Wadden Council (Raad voor de Wadden) published advice on the applicability of natural limits (RVDW, 2007). They gave a definition for natural limits in which human activities play a more prominent role: "*a system of limits for the most important natural parameters, linked to human activities, for which scientific consensus exists that as long as these limits are not exceeded, natural processes in the Wadden Sea would go undisturbed*". The Council concluded that there should be a system of limits to human use, agreed upon by society, for which the effects of human use lie in between minimum and maximum threshold values for significant change of ecosystems (Figure 1).

Various workshops have been held with experts and policy makers in an effort to elaborate on a system of natural limits. However, there has been a lot of discussion and also confusion on definitions. Should we speak of 'natural limits' or rather 'user limits'? Are the limits set by the natural processes of the Wadden Sea, or rather by policy makers? And, last but not least, how do we quantify these limits in the light of the complexity and dynamics of the Wadden Sea ecosystem, and will they stand in legal procedures?

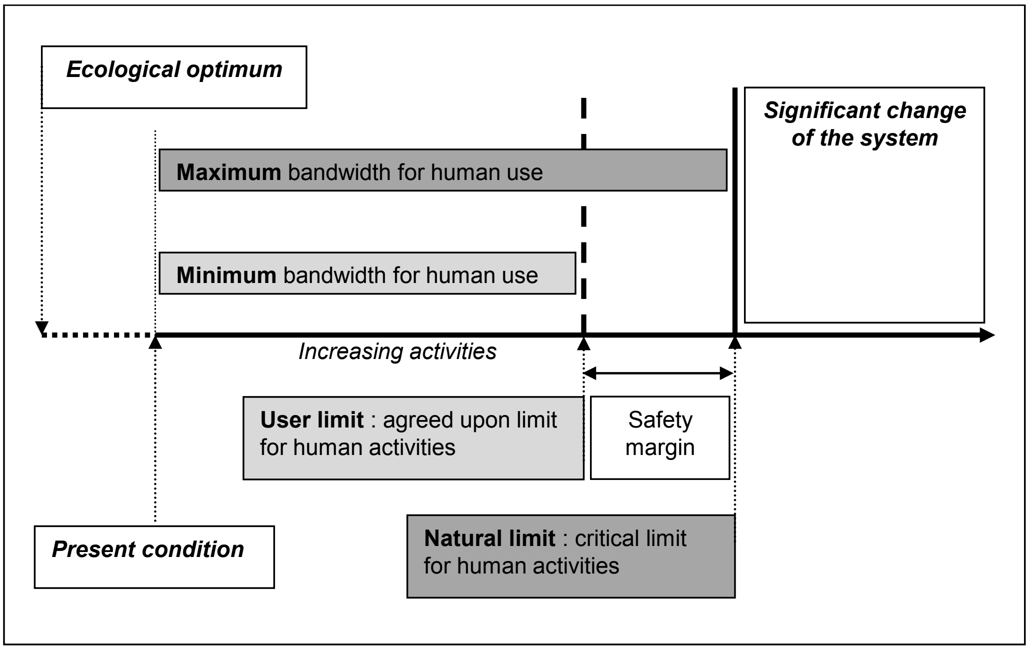

Figure 1: Relational scheme for natural limits and user limits. A natural system has a present condition, which is less than the ecological maximum. For increasing levels of activities, the system moves away from the maximum towards a critical threshold value, beyond which significant change of the system occurs. Two different limits can be defined for human activities. The natural limit, in strict sense, is the critical threshold for significant changes to the natural system. In fact, the user limit is an agreed limit up to which it is certain that no significant changes occur. In between the present condition and the limits, bandwidths of human use can be defined. After Swart and Van der Windt (2007).

In this study the feasibility of the proposed framework is evaluated from an ecological and juridical perspective. Two types of limits were distinguished, those set by law and policy, such as the EU Habitats and Birds Directives or the trilateral Eco-targets, and those set by ecological knowledge, such as carrying capacity and minimal viable population size. For salt marshes, mussel beds, bird populations and EU habitat type 1140 (intertidal areas) available knowledge was studied in more detail and an attempt was made to define limits based on natural processes.

2. Elaboration on natural limits

From analyzing documents and discussion sessions on natural limits we concluded that two main types can be distinguished:

1. Natural limits that follow from political or policy decisions; they are documented in the EU Habitats and Birds Directives, the Water Framework Directive, the trilateral Eco-targets or other documents. They specify minimum areas of habitats, or minimum habitat quality, or minimum size of bird populations needed for a good status of the ecosystem. They have been specified on the basis of ecosystem knowledge, however, they differ from Type 2:
2. Natural limits that follow from ecosystem properties, such as carrying capacity, minimal viable population size or tipping point of a regime shift; they are established on the boundaries of ecosystem components based upon ecological thresholds. Two subtypes can be distinguished:

a. Endogenic natural limits, determined by the boundaries of the range of natural variability within which the ecosystem component exists.

b. Exogenic natural limits, determined by processes and (a)biotic characteristics of environmental variables that serve as boundary conditions to an ecosystem component.

In our view, and in compliance with the definition of the Dutch Advisory Committee on Wadden Sea Policy, Type 2 is the true natural limit or threshold. Therefore, when the aim is to conserve certain ecosystem characteristics, human pressure on the ecosystem should never be so large that this limit is reached and a significant change of the system occurs. In practice, a safety margin is applied, and additional political reasoning will establish limits of Type 1. We suggest that ultimately limits to human use will be defined in such a way that the true natural limits are not exceeded. Conforming with the definition of the Dutch Wadden Council, we prefer to call these limits 'user limits', see Figure 1. An example is gas extraction in the Wadden Sea. Subsidence is the major problem so this activity is allowed as long as it does not exceed the natural sedimentation rate (a Type 2b natural limit) leading to drowning of litoral mudflats (a Type 2a natural limit). In this case the natural sedimentation rate is the natural limit to subsidence and thus to the amount of gas to be extracted. Due to coinciding sea level rise and safety margins the user limit is lower than the natural limit. The gas is extracted with "the hand on the tap"; if limits are exceeded the gas extraction is stopped.

Table 1: Natural limits for salt marshes.

Parameter	Limit.	Type
Size of a salt marsh	Minimum size is 500 ha.	2a
Drainage and ponds	Drainage channels naturally developed and maximum 10% of salt marsh area. Ponds are part of a natural salt marsh, total surface area maximum 6% and maximum size 1250 m2 or wind fetch 80 m.	2a
Optimal distribution of habitat types	H1310 (pioneer) ca. 5-25 % (with cover> 5%) and H1330 (well-developed) ca. 75%.	1
Optimal distribution of vegetation zones	All possible zones have to be present with a distribution of minimum 5% and maximum 40% (at a total of 4 zones) or 35% (at a total of 5 zones).	1
Sediment balance deficit	Maximum sediment balance deficit < 5-15 cm.	2b

We have elaborated and defined natural limits for a number of ecosystem components in the Wadden Sea, i.e. salt marshes, intertidal sand flats and mudflats, intertidal mussel beds, and food availability for birds and will give examples of Type 1 and Type 2 natural limits, where possible.

2.1 Salt marshes (habitats 1310 and 1330)

Natural limits for salt marshes can be defined for their quantity and for their quality. A certain minimum size is required to have diversity of geomorphology and biotopes, and to give room for processes of natural rejuvenation. Beeftink (1984) defined a minimum size of 500 ha per site, which is a Type 2a natural limit.

The quality of a salt marsh is determined by the relative area of vegetation zones. Dijkema *et al.* (2005a) defined a set of (natural) limits to different vegetation zones to be used for the Water Framework Directive. They state that the relative distribution of each zone should lie between a minimum of 5% and a maximum of 35% (with five vegetation zones) or 40% (with four vegetation zones). Furthermore, climax-vegetation may not dominate (more than 50% cover) within its zone. Together with similar limits for Natura 2000 habitat types, these are examples of Type 1.

Regression from one vegetation type to another can be a natural phenomenon, but two phenomena in particular are unwanted since they will lead to an unstable or unvegetated and therefore potentially erosive situation:

1. regression from a low salt marsh (with sediment stabilizing *Puccinellia*) to a pioneer zone (with *Salicornia*).
2. regression from a pioneer zone to a bare flat.

For the salt marshes of The Netherlands, theoretical lower limits for the height of the marsh (relative to Dutch Ordnance Level) have been defined (e.g. van Duin *et al.*, 1997). These can be viewed as a Type 2a limit: their endogenic natural limits. Due to sea level rise and soil subsidence, the relative height may decrease and unwanted regression may occur. The zonal hypothesis states that a change in vegetation type will occur due to relative sea level rise when the sedimentation rate lags behind. Oost *et al.* (1998) stated that there are no changes in vegetation type when the sediment balance deficit is temporary and smaller than 5 cm. Recent findings showed that in some cases a sediment deficit of as much as 15 cm had no consequences for the vegetation (Dijkema *et al.*, 2005b). The sediment balance deficit for which the salt marsh is still able to exist can be considered as a Type 2b limit: the exogenic natural limit. Research into soil subsidence due to gas extraction on the salt marshes of Ameland has shown that not only the sediment balance, but also the drainage and the grazing management have a profound effect on the vegetation zoning. This makes the definition of generic natural limits more complicated.

Finally, limits have been set for the percentage and maximum size of ponds within saltmarsh systems by Van Duin *et al.* (2003): the total surface area of ponds may not exceed 10% and the size may not exceed 50 x 25 m, or have a maximum wind fetch of 80 m length. These limits have been based on analysis of natural salt marsh systems and are examples of Type 2a limits. A summary of natural limits for salt marshes is presented in Table 1.

2.2 Intertidal sand flats and mudflats (habitat 1140)

Natural limits for H1140 can theoretically be defined for its quantity and for its quality, similar to saltmarshes. Cleveringa and Oost (1999) studied fractal patterns in the tidal basins of the Wadden Sea and defined a minimum tidal volume for sustainable existence of a tidal basin at 55 million m^3. This is a Type 2a natural limit.

Due to relative sea level rise, the hydrography of a tidal basin changes and the basin will attempt to import sediment to maintain an equilibrium state. The rate at which sedimentation can keep up with the rate of SLR is a Type 2b natural limit and is estimated at 5 to 6 mm/year for the Dutch eastern Wadden Sea.

The quality of H1140 is dependent on many abiotic and biotic factors. Natural limits for the quality of H1140 are, therefore, hard to define. Moreover, the natural dynamics in quality parameters such as species abundance, presence of biogenic species or sediment composition are very large. Type 2 natural limits can possibly be defined on the basis of an ecosystem approach in which the ecological functioning of food webs and nutrient cycling form a basis. A conclusive system, however, has not been developed yet. Therefore, only Type 1 natural limits, based mainly on quantity, can be used at this moment.

2.3 Intertidal mussel beds (quality criterion for H1140)

An intertidal mussel bed is defined as: "a benthic community in which mussels (*Mytilus edulis*) are dominant (>5% cover) and in which a spatially well-defined structure of large and small groups of mussels exists, rising above the surrounding sediment and separated by open spaces" (Brinkman *et al.*, 2003). This definition can be seen as a Type 2a natural limit. Compared to salt marshes, the dynamics in structure and shape of mussel beds are highly variable.

Mussel beds exist of mixed age classes that originate from years with successful recruitment. The size and structure of beds are continuously changing due to growth and loss of mussels. The maximum age of mussel beds can range over 10 years (Goudswaard *et al.*, 2006), however, approximately 50% of the area of mussel beds does not become older than 1 year and another 25% does not become older than 2 years (Fey *et al.*, 2008). Older banks show a vertical profile of dead shells, mixed with faeces and pseudofaeces, sand and organic detritus underneath and about 40% live shells on top (Fey *et al.*, 2008; Dankers *et al.*, 2004).

The stability of mussel beds is determined by many factors, such as the age of the bed, the shell-density, the adherence of the byssus-threads, the bed structure, the height of the bed and the stability of the sediment underneath the bed. For the (long-term) survival of mussel beds, many more factors come into play, such as: biological factors (spatfall, recruitment, predation), abiotic factors (inundation period, temperature, salinity, dissolved oxygen, flow velocity, wave exposition, position of the gullies, predominant wind direction). The long list makes it clear that Type 2b natural limits are based on multivariate factors and are hard to define.

2.4 Food availability for bird populations

The quantity of food necessary to support a population of birds can be seen as a natural limit. Such a limit depends upon species, time (period of wintering, moulding, breeding, etc.) and space (roosting areas, food availability nearby, etc.). Furthermore, intraspecific competition plays a role.

At the same time shellfish fishermen harvest mussels and cockles, an important food source for the birds. A major question is: how many shellfish can be harvested annually without creating food limitation for birds. Calculating the natural limits and setting user limits helps to prevent starvation of birds due to exploitation of their food sources.

There are several models that predict the necessary quantity of food for birds (Brinkman *et al.*, 2007). The *generalized functional response* describes the intake rate of food as a function of the density of prey and of competition. Under the assumption of *ideal free* (Fretwell and Lucas Jr., 1970; Sutherland, 1996) behaviour, this leads to predictions on the distribution of birds in their foraging area, the so called *aggregative numerical response* (Van der Meer and Ens, 1997). An important difference must be made between the physiological and the ecological need for food. The ecological need is determined by the amount of food that is physiologically needed and that is available for foraging.

As an example we take the oystercatcher (*Haematopus ostralegus*), which mainly feeds on bivalves. For oystercatchers, Rappoldt *et al.* (2003) found that 3.1 times more food needs to be present in the Wadden Sea than is required for physiological purposes. Wintering oystercatchers need 360 g/day flesh weight of bivalves, a Type 2a natural limit. To support a population of 216,000 birds over a period of 250 days/year (the conservation objective for the Dutch Wadden Sea, a Type 1 limit), a minimum quantity of 0.36 kg/day x 250 days x 216,000 birds x 3.1 (ecological need factor) = 60 million kg flesh weight is needed in total.

By monitoring the annual occurrence of mussel beds and cockles and the number of oystercatchers, both needed and available amount of bivalves can be calculated. If the needed amount is exceeded, shellfish fisheries can be allowed, and from the natural limit calculated above, a user limit can be set and harvested. In principle, such simple natural limits can be derived for more species of shorebirds, however, for many species knowledge is lacking, especially when they feed on a multitude of prey species.

3. Juridical assessment

The Natura 2000 regime requires that conservation targets are set for all sites designated under the European nature protection directives. The targets for a site particularly relate to safeguarding favourable conservation status for species and habitat types for which the site received its European status. The implementation legislation of the Member State must ensure that human activities will only be authorised if, on the basis of an assessment, it is concluded that such activities will not frustrate the conservation targets of the relevant site. In case of uncertainties ('reasonable doubts'), a plan or project may not be authorised.

The development of natural limits fits very well in this system. Particularly if the natural limits are related to the ecological characteristics and qualities that constituted the reason for designating the site, such limits can underpin the implementation of the legal regime. In fact, the natural limits constitute the ecological basis for monitoring ongoing activities and for assessing plans and projects that may affect the site.

A next step - setting user limits for human activities on the basis of natural limits - is to avoid unnecessary assessments, procedures and related costs; however, we conclude that such an approach will almost certainly raise conflicts with the legal requirements. Tailor work (concrete assessments of each plan and project) is required due to various factors, such as the complexity of ecological systems, the requirement to take into account cumulative impacts when assessing the effects of a plan or project, and the required application of the precautionary principle (absence of reasonable doubts). Nonetheless, as stressed above, the natural limits may substantially support such individual assessments and may to a certain extent limit costs because assessments can be based on the already available knowledge regarding natural limits. To have these advantages over a longer period of time, monitoring and continuous research efforts to increase best available knowledge regarding the natural limits are crucial.

4. Implementation of natural and user limits

We defined two main types of natural limits and deduced a third type, that of 'user limits'. To improve the practical use, we propose the following set of definitions:

The *natural limit* is determined by the value(s) for (a) characteristic (environmental) variable(s) at which level a pre-defined ecosystem component or feature complies with its definition. Exceeding the natural limit leads to a significant effect upon the ecosystem component.

The *user limit* is determined by the agreed value(s) for an activity at which level the characteristic (environmental) variables are not significantly affected. Exceeding the user limit may lead to a significant effect upon the ecosystem component.

We propose the following steps when implementing a system of natural and user limits:

1. Define and quantify the ecosystem component and its qualifying variables (its endogenic natural limits).
2. Define the limits of the processes and (a)biotic characteristics of environmental variables that serve as boundary conditions (the exogenic natural limits).
3. Define the limits of external human factors that influence the ecosystem component and may force it beyond its definition (the ultimate user limits).
4. Define the politically agreed limits for human activities in space and time.

User limits can be made flexible in both time and space. The combination of changing environmental and human conditions and flexible user limits can only be managed by a form of adaptive management and monitoring. We therefore propose as subsequent steps:

5. Define monitoring parameters both for ecosystem parameters and human uses.
6. Define flexible user limits by comparing monitored system parameters with natural limits, including natural system dynamics.

5. Conclusions

We conclude that a generic set of natural limits, valid for the entire Wadden Sea and for every activity is not feasible. There are too many intricate and unknown inter-relationships to reach this goal. However, site- and species-specific limits can be defined to enable appropriate assessments for new activities in the Natura 2000 regime. Furthermore, we conclude that knowledge of resilience and uncertainty needs to increase in order to define natural limits and 'significant effects' of activities. We finally recommend application of appropriate monitoring and adaptive management tools in a framework of flexible user limits to support a sustainable balance between human use and nature.

References

Beeftink, W.G., 1984. Geography of European halophytes. In: Dijkema, K.S. (ed.), W.G. Beeftink, J.P. Doody, J.M. Gehu, B. Heydemann and S. Rivas Martinez. Salt marshes in Europe. Council of Europe. Nature and environment series 30, Strasbourg: 15-33.

Brinkman, A.G., T. Bult, N. Dankers, A. Meijboom, D. den Os, M.R. van Stralen and J. de Vlas 2003. Mosselbanken: kenmerken, oppervlaktebepaling en beoordeling van stabiliteit. Alterra rapport 707. 70 pgs/ EVA-II rapport (in Dutch).

Brinkman, A.G., J.J. de Leeuw, M.F. Leopold, C.J. Smit, C.J. and I.Y.M. Tulp, 2007. Voedselecologie van een zestal schelpdieretende vogels. IMARES rapport C078/07 (in Dutch).

Cleveringa, J. and A. Oost, 1999. The fractal geometry of tidal-channel systems in the Dutch Wadden Sea. Geologie en Mijnbouw 78: 21-30. DOI 10.1023/A:1003779015372.

Dankers N., A. Meijboom, M. de Jong, E. Dijkman, J. Cremer, S. van der Sluis, 2004. Het ontstaan en verdwijnen van droogvallende mosselbanken in de Nederlandse Waddenzee. Alterra-rapport 921. Alterra-Wageningen (in Dutch).

Dijkema, K.S., D.J. de Jong, M.J. Vreeken-Buijs and W.E. van Duin, 2005a. Kwelders en schorren in de Kaderrichtlijn Water. Ontwikkeling van Potentiële Referenties en van een Potentieel Goede Ecologische Toestand. Alterra-Texel, WageningenUR; Rijkswaterstaat, Rijksinstituut voor Kust en Zee, Middelburg; Rijkswaterstaat, Adviesdienst Geo-informatie en ITC, Delft. RIKZ/2005.020. 62 p. (in Dutch).

Dijkema, K.S., W.E. van Duin and H.F. van Dobben, 2005b. Kweldervegetatie op Ameland: effecten van veranderingen in de maaiveldhoogte van Nieuwlandsrijd en De Hon. In: Monitoring effecten van bodemdaling op Ameland-Oost. Evaluatie na 18 jaar gaswinning. Begeleidingscommissie Monitoring Ameland. 97 p.

Fey, F.E., J.M. Jansen, E.M. Dijkman, J.J. Kesteloo, 2004. Ruimtelijke verspreiding van sublitorale mosselvoorkomens en mosselzaadvisserij van 1997 – 2007. Texel/Yerseke, IMARES Rapport C102/08 (in Dutch).

Folke, C., S. Carpenter, B. Walker, M. Scheffer, T. Elmqvist, L. Gunderson and C. S. Holling, 2004. Regime shifts, resilience, and biodiversity in ecosystem management. Annual Review of Ecology, Evolution, and Systematics 35: 557-581.

Fretwell S.D. and Lucas H.L. Jr., 1970. On territorial behavior and other factors influencing habitat distribution in birds. I. Theoretical development. Acta Biotheoretica, XIX, 16-36.

Goudswaard, P.C., J. Steenbergen, J.M.D.D. Baars, J.J. Kesteloo-Hendrikse, J.G.Jol, M.R. van Stralen, 2006. Het mosselbestand en het areaal aan mosselbanken op de droogvallende platen in de Waddenzee in het voorjaar van 2006. Ijmuiden, IMARES Rapport C059/06 (in Dutch).

Meijer, W., P.C. Lodders-Elfferich and L.M.L.H.A. Hermans, 2004. Ruimte voor de Wadden. 's Gravenhage, Adviesgroep Waddenzeebeleid (in Dutch).

Oost, A.P., Ens, B.J., Brinkman, A.G., Dijkema, K.S., Eysink, W.D. , Beukema, J.J., Gussinklo, H.J., Verboom, B.M.J. and Verburgh, J.J., 1998. Integrale Bodemdalingsstudie Waddenzee. Instituut voor Aardwetenschappen, Universiteit Utrecht (UU), Utrecht, Instituut voor Bos- en Natuuronderzoek (IBN-DLO), Texel, Waterloopkundig Laboratorium (WL | delft hydraulics), Delft, Nederlands Instituut Onderzoek der Zee (NIOZ), Texel, Nederlandse Aardolie Maatschappij B.V. (NAM), Assen (in Dutch).

Rappoldt C, Ens B.J., Dijkman E.M., and Bult T., 2003. Scholeksters en hun voedsel in de Waddenzee. Rapport voor deelproject B1 van EVA II, de tweede fase van het evaluatieonderzoek naar de effecten van schelpdiervisserij op natuurwaarden in de Waddenzee (in Dutch).

RVDW, 2007. Natuurgrenzen voor dagelijks gebruik; advies over de toepassingsmogelijkheden voor natuurgrenzen. Raad voor de Wadden, Advies 2007/03 (in Dutch).

Sutherland W.J., 1996. From Individual Behaviour to Population Ecology. Oxford University Press, Oxford.

Swart, J.A.A. and H.J. van der Windt, 2007. Essay over natuurgrenzen. Bijlage 2 bij Advies 2007/03 Raad voor de Wadden. Rijksuniversiteit Groningen, Afdeling Wetenschap en Samenleving (in Dutch).

Van der Meer J. and Ens B.J., 1997. Models of Interference and Their Consequences for the Spatial Distribution of Ideal and Free Predators. Journal of Animal Ecology, 66, 846-858.

Van Duin, W.E., K.S. Dijkema and J. Zegers, 1997. Veranderingen in bodemhoogte (opslibbing, erosie en inklink) in de Peazemerlannen. IBN-rapport 326. 104 p.

Van Duin, W.E. and Dijkema, K.S., 2003. Proef met de onderhoudsarme ontwatering in de kwelderwerken: "de Krekenproef"; evaluatie 1997-2002. Wageningen, Alterra. Alterra-rapport 634. 137 p. (in Dutch).