Disturbance-effect relationships applied in an integral Ecological Risk Analysis for the human use of the North Sea

Summary in English of Jak *et al.* (2000)

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Report numberC011/09

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Publication Date: February 2, 2009

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Contents

1 Introduction

The relationship between the intensity of seven types of human based disturbances and their resulting effects on survival and reproduction of 30+ species were described as a function of increased mortality or reduced reproduction in the report of Jak et al 2000. The numerical values of the parameters in these functions were, as far as possible, estimated on the basis of data from literature, dealing with the sensitivity of the considered species, or otherwise of related species or biota in general, for the regarded disturbance. The disturbance-effect relationships were applied in an integral ecological risk analysis for human activities at the North Sea: RAM (Risk Analysis instrument for the Marine environment). The aim of RAM was to rank the human activities on the basis of their environmental risk. The RAM – GIS model was developed in the nineties by the National Institute of Coastal and Marine Management / RIKZ (currently part of Deltares), in cooperation with TNO (currently part of IMARES), WL (currently part of Deltares) and Geodan (Karman et al. 2001). These reports were written in Dutch.
The data from this project could be of use in the process of QSR 2010. Therefore, the data from this study was summarised and translated into English.

Chapter 2 gives a brief overview of the RAM methodology. Although these technical details will not primarily contribute to the overview of data, it describes the general approach and will contribute to the understanding of data. These data are presented in chapter 3. Each paragraph relates to an impact theme as defined in the QSR process. The human based activities as described in the report of Jak et al (2000) are discussed concerning these impact themes.

Not all impact themes were addressed within Jak et al 2000. The following themes were addressed:

- Pollution and other chemicals
- Species level impacts on condition
- Species level impacts on distribution/population size
- Habitat damage
- Habitat loss

Climate change, hydrographic change, and other impacts as litter were not addressed and thus not incorporated in this summary. Sub-impact descriptions were not always covered in total. E.g., in case of the theme "Pollution" five different kinds of pollution are to be considered, whereas Jak et al (2000) only reflected two of these.

It should be noted that this summary in English only reflects the data as used and presented by Jak et al 2000, and that no update of data has been done by the present authors.

2 Methodology

The RAM methodology comprises the disturbance and effect chain from activity to species (Figure 1) and can be described in five steps (Karman et al. 2001):

1. quantifying the potential exposure
2. combining each potential exposure with a specific disturbance-effect relationship
3. integrate the effects of all potential exposures
4. combine effects of mortality and reproduction to derive a single population measure
5. analyses of the results: the ranking of disturbances and human activities based on their ecological risk.

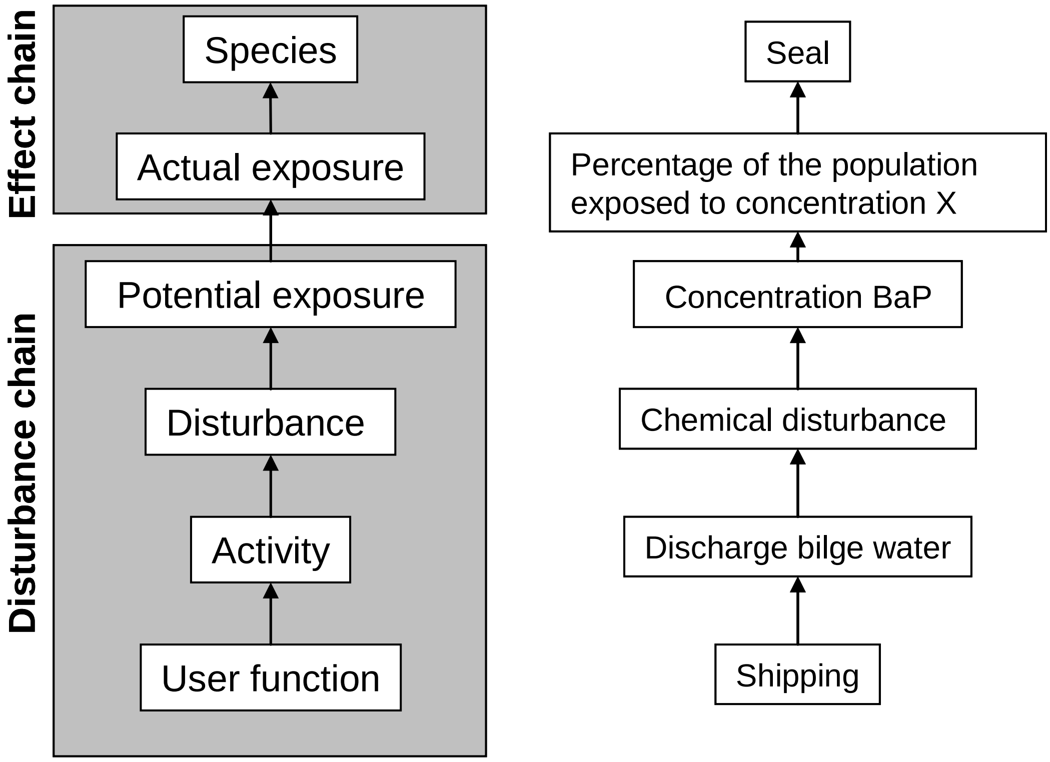

Figure 1 RAM schedule, showing the applied terminology (left) and example (right). Translated from (Karman et al. 2001).

2.1 Exposure

The disturbances (i.e. pressures) identified within RAM are presented in Table 1. These generally correspond to the pressures as identified within the Marine Strategy Framework Directive (MSFD) (EC 2008).

Table 1 Pressures included in Jak et al 2000

Pressure	Impact
Chemical pollution	Exposure through water phase
	Exposure through food
	Exposure to floating layers (i.e. oil)
Eutrophication	Exposure to reduced oxygen concentrations resulting from degradation of organic (algae) material
Mechanical disturbance	Exposure to (5) different types of fishing gear on the seabed
	Exposure to increased concentration of suspended matter in the water column
	Exposure to the deposition of a layer of sediment with a thickness > 20 cm
	Trampling by humans
Extraction of species	Extraction of target and non-target species by fishing
	Extraction of benthic species by dredging and aggregation
Change in substrate	Permanent change in hard substrate or gravel
Acoustic disturbance	Exposure to (continuous) noise
	Exposure to shock waves
Visual disturbance	Presence of humans; boats; airplanes; constructions; and flairs.

Only those impacts directly affecting two population dynamical parameters of the relevant species were considered in RAM: mortality and (re)production (Jak et al. 2000, Karman et al. 2001).

2.2 Disturbance-effect relationships

The relationship between the intensity of seven types of human based disturbances and their resulting effects on survival and reproduction of selected "AMOEBE[1]-species" (Table 2) has been described with simple functions. The values of the parameters in these functions were, as far as possible, estimated on the basis of data from the literature, dealing with the sensitivity of the considered species, or otherwise extrapolated from data on related species or biota in general, for the regarded disturbance.

Furthermore, the “suitability” of information was given a score to reflect the uncertainty of parameter values. Factors contributing to the ‘suitability” were, e.g., the amount of information available, and the comparability of the published results with the parameters used to describe the dose-response relationships. The uncertainty scores were applied to calculate minimum and maximum values around the parameter value, and thus reflect the uncertainty range.

*Table 2 Species of which the disturbance-effect relationships have been determined for implementation in RAM. Species underlined are not AMOEBE species and species marked with * have not been included in the final output (i.e. ranking of disturbances) of RAM (Jak et al. 2000)*

Species group	Common name	Scientific name	Related Ecosystem Component
Mammals	Common seal	*Phoca vitulina*	Pinnipeds
	Harbour porpoise	*Phocoena phocoena*	Cetaceans
	Bottlenose dolphin	*Tursiops truncatus*	Cetaceans
Birds	Oystercatcher	*Haematopus ostralegus*	- (Waders)
	Sandwich tern	*Sterna sandvicensis*	Seabirds
	Avocet	*Recurvirostra avosetta*	- (Waders)
	Guillemot	*Uria aalge*	Seabirds
	Fulmar	*Fulmaris glacialis*	Seabirds
	Brent goose	*Branta bernicla*	Seabirds
	Dunlin	*Calidris alpina*	- (Waders)
	Kentish / snowy plover	*Charadrius alexandrinus*	- (Waders)
	Common eider	*Somateria mollissima*	Seabirds
Fish	Sturgeon	*Acipenser sturio*	Fish
	Herring	*Clupea harengus*	Fish
	Thornback ray	*Raja clavata*	Rays sharks
	Cod	*Gadus morhua*	Fish
	Plaice	*Pleuronectes platessa*	Demersal Fish
	*Sandeels	*Ammodytes* spp.	Demersal Fish
Echinoderms	Heart urchin	*Echinocardium cordatum*	Seabed habitats
Molluscs	Baltic telling	*Macoma balthica*	Seabed habitats
	Common mussel bed	*Mytilus edulis*	Seabed habitats
	Sand gaper	*Mya arenaria*	Seabed habitats
	Common cockle bed	*Cerastoderma edule*	Seabed habitats
	Dog whelk	*Nucella lapillus*	Seabed habitats
	Icelandic cyprine	*Arctica islandica*	Seabed habitats
Hydroids	Plumose anemone	*Metridium senile*	Seabed habitats
Bentic crustaceans	Brown shrimp	*Crangon crangon*	Seabed habitats
	Lobster	*Homarus vulgaris*	Seabed habitats
	*Flying crab	*Liocarcinus holsatus*	Seabed habitats
Annelid worms	Capitellid thread worm	*Heteromastus filiformis*	Seabed habitats
	*Trumpet worm	*Pectinaria koreni*	Seabed habitats
Algae	Sugar kelp	Laminaria saccharina	Seabed habitats
	Channel wreck	*Pelvetia canaliculata*	Seabed habitats
	Sea lettuce	*Ulva* spp.	Seabed habitats
	Total algae		Seabed habitats
Zooplankton	Copepodes		Seabed habitats
Vegetation	Seagras	*Zostera* spp.	Seabed habitats
	*Meadow (sea-aster/glasswort)	*Aster tripolium / Salicornia* sp.	

An exposure matrix has been developed indicating the relevant exposure types of disturbances to species. For the relevant exposures, disturbance-effect relationships have been established.

The disturbance-effect relationships describe the relation between the intensity of a potential exposure (e.g. the cadmium concentration in water) and the effect on the survival or reproduction on a species. The effect is expressed as a fraction between 0 and 1:

Fraction Effect = f (Exposure intensity)
Under the preconditions:

- if the exposure intensity = 0, than effect = none = 0
- if the exposure intensity = maximum, than effect = maximum = 1

Many types of functions can describe the above relationships, i.e. logistic curve, linear relation, etc. An appropriate function type per pressure/impact has been selected (Table 3), which is applicable for all relevant species. Therefore, for each pressure, only the values of the parameters differ per species. The function has been quantified based on several calibration points, which have been derived from literature information on the sensitivity of the species for that pressure/impact.

A few general parameters have been used as much as possible in the different functions:

m = median effect intensity, intensity of disturbance at which effect = 50%
d = threshold value, disturbance intensity at which effect will occur
c = intensity-effect coefficient, indicating the slope of the function

The variables are:

y = *the effect on survival and/or reproduction (fraction between 0 and 1)*
x = *the disturbance intensity of the potential exposure.*

Table 3 The function type and related parameters as applied in the description of the disturbance-effect relationships of the different pressures (Jak et al. 2000)

Function type	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Parameters	**m, c**	**d**	**c, d**	**c, d**	**c**	**c**	**c, d**
Toxicants in water	**X**						
Toxicants in food	**X**						
Hypoxia			**X**				
Trawling					**X**		
Increased SPM and turbidity			**X**	**X**			
Smothering						**X**	
Trampling					**X**		
Fishery		**X**					
Dredging and aggregation						**X**	
Noise				**Not included**			
Shok wave				**Not included**			
Visual disturbance							**X**
Removal of hard substrate						**X**	
Removal of gravel						**X**	

1 = logistic function
2 = negative linear relation without threshold
3 = negative linear relation with threshold
4 = positive linear relation with threshold
5 = random probability function
6 = homogenic probability function
7 = visual disturbance function

The functions and relationships are explained in more detail in ANNEX 1.

2.3 Integration of effects and the derivation of a single population measure

Deriving and calculating all relevant disturbance-effect relationships resulted in a large amount of parameter values. In order to derive conclusions from this extensive data set, further analysis was conducted.
Next steps were to integrate the effects of all potential exposures and combine mortality with reproduction to derive a single population measure.

The integral effect was calculated according to the function:
Integral effect (A+B) = effect (A) + effect (B) – effect (A) * effect (B)

The 'replacement value' has been used as population measure and is defined as: *"The number of adult individuals that is expected to be produced by a new adult during the rest of its live as adult".*
The replacement value = survival juveniles * number of years as adult * reproduction
It is assumed that within a stable situation (without anthropogenic influence) the replacement value equals 1, based on natural mortality and reproduction rates assessed from literature information. By using mortality and reproduction as end-points in the effect assessment, a new replacement value was calculated, which is representative for the disturbance of concern.

3 Results

All disturbance-effect relationships as identified in the previous chapter have been quantified and implemented within RAM. The database of parameter values is unique in the sense that for 35 species all relevant disturbance-effect relationships are quantified, even though it concerns to a great extent provisional estimates which can be specified with increasing knowledge and data.

3.1 Pollution and other chemicals

Impact theme pollution and other chemicals (OSPAR) regard the impacts of
- Non-synthetic compound contamination (heavy metals, hydrocarbons (incl. produced water);
- Synthetic compound contamination (incl. pesticides, antifoulants, pharmaceuticals);
- Radionuclide contamination;
- De-oxygenation;
- Input of nitrogen & phosphorus;
- Organic enrichment
- All other substances, whether solid, liquid or gas.

Compound contamination by both non-synthetics and synthetics, eutrophication in terms of de-oxynation were described and analyzed by Jak et al. 2000 and summarized below.

3.1.1 Compound contamination: (non)-synthetics

Introduction of (non-) synthetic compounds could be e.g. from oil and gas production facilities, land-based activities or shipping. Within dose response descriptions regarding the responses of pollution the responses can be caused in several pathways. These are via water, food, or floating layers. Only dose-response relations via pathway of water are discussed in this report. To quantify effects via toxicants in water the literature data are believed to represent dissolved concentrations. Only data concerning lethal effects were used. Reproduction effects were calculated using an empiric ratio between LC50 en NOEC (reproduction) (Heger et al 1995). An empirical value for the slope was established by Smit et al. (1995).

In Table 4 the mean lethal effect intensity (*m*) of disturbance by compounds to different ecosystem elements (species) is given. The dose response relationships of contaminants and organisms were described with a logistic function (see Annex 1).

Table 4 The median effect intensity m (LC50 in µg/l; intensity of disturbance by a specific compound at which the effect = 50%) for different ecosystem elements and non-synthetic compound contamination - Heavy metals, Hydrocarbons , and synthetic compounds (adapted from Jak et al 2000).

Compound	Fish	Fish - pelagic	Fish - demersal	Fish - sharks, skates & rays	Fish - deep sea	Fish - migratory	Phytoplankton	Zooplankton	Intertidal biogenic reef	Intertidal seagrass beds	Macrophyte-dominated subtidal sediment
Cd	19715	14000	19715	19715	19715	14000	16916	398	2191	16916	16916
Cr	66500	66500	66500	66500	66500	66500	1036	19270	83332	1036	1036
Cu	1015.3	172	1015.3	1015.3	1015.3	1015.3	41	134	136	41	41
Hg	553	553	553	553	553	553	18	21	161	18	18
Pb	1694	1694	17297	1694	1694	1694	60000	640	538	729	729
Ni	64330	64330	64330	64330	64330	64330	1656	6000	11926	1656	1656
Zn	35810	35810	35810	35810	35810	35810	2330	1212	5750	2330	2330
mineral oil	3850	1862	3850	3850	3850	3850	11920	10350	233	11920	11920
PAHs	1313	1313	1313	1313	1313	1313	7038	2.6	3194	7038	7038
hexachlorbenzene	3151	3151	3151	3151	3151	3151	762	16	762	762	762
hexachlorethane	1386	1386	1386	1386	1386	1386	2486	16	2486	2486	2486
Acrylonitril	24214	24214	24214	24214	24214	24214	22157	10266	22157	22157	22157
Analine	65376	65376	65376	65376	65376	65376	42630	339	282843	42630	42630
Atrazine	20762	20762	20762	20762	20762	20762	14148	94	14148	14148	14148
Azinfos	63	63	63	63	63	63	32	8.5	32	32	32
DNOC	351	351	351	351	351	351	736	652	736	736	736
Endosulfan	0.7	0.7	0.7	0.7	0.7	0.7	2.9	2.9	2.9	2.9	2.9
Ethylenechloride	86629	86629	86629	86629	86629	86629	112551	140676	112551	112551	112551
HCH	54	54	54	54	54	54	66	312	3199	66	66
Malathion	209	209	209	209	209	209	218	665	6000	218	218
Parathion	875	875	875	875	875	875	234	0.8	2480	234	234
PCB's	3.6	3.6	3.6	3.6	3.6	3.6	9.9	13	10	30	30
TBT	12	12	12	12	12	12	5.9	1	22	5.9	5.9
Trifenyltin	112	112	112	112	112	112	123	27	220	123	123

3.1.2 Eutrophication (de-oxynation)

Low oxygen concentrations can arise in summer at places with decomposition of organic matter. It can happen near the bottom, but as well in the water layer just underneath the thermocline, or algal blooms. In the coastal areas mixing of the water layer will prevent problems with oxygen depletion. In deeper areas, it depends on local conditions. With total lack of oxygen H_2S can be produced, and contribute to the impact of eutrophication. In Table 5 estimated threshold values (days) and fraction of the effect (mortality) at situations oxygen concentrations below 3 mg/l are presented. The dose response relationship of de-oxynation and organisms was described using a negative linear relation with threshold (see Annex 1).

Table 5 Estimated threshold values (d in days) and slope (c; effect size) to the lethal effects at an oxygen concentration below 3 mg/l

Mortality	**Threshold value (days)**			**Effect size**		
Species	***d***	**min**	**max**	***c***	**min**	**max**
Herring	1	0.45	2.21	0.5	0.21	0.79
Ray	1	0.45	2.21	0.5	0.21	0.79
Cod	1	0.45	2.21	0.5	0.21	0.79
Plaice	3	1.36	6.62	0.5	0.21	0.79
Sand eel	3	1.36	6.62	0.5	0.21	0.79
Heart urchin	6	3.06	17.45	0.2	0.06	0.77
Baltic tellin	7	3.17	15.45	0.2	0.09	0.66
Mussel bed	15	6.80	33.11	0.2	0.09	0.66
Sand gaper	7	3.17	15.45	0.2	0.09	0.66
Cockle bed	4	1.81	8.83	0.5	0.21	0.79
Iceland cyprice	50	19.91	110.35	0.1	0.04	0.68
Plumose anemone	3	1.03	8.72	0.2	0.06	0.77
Brown shrimp	2	0.91	4.41	0.5	0.21	0.79
Lobster	2	0.69	5.82	0.5	0.06	0.77
Flying crab	2	0.69	5.82	0.5	0.06	0.77
Threat worm	15	6.80	33.11	0.05	0.02	0.59
Trumpet worm	12	4.78	30.14	0.1	0.04	0.68
Zooplankton	1	0.45	2.21	0.5	0.21	0.79

Table 6 Threshold values (d; in days) and slope (c; effect size) regarding effects on reproduction at oxygen concentration below 3 mg/l

Reproductie	**Threshold value (days)**			**Effect size**		
Species	***d***	**min**	**max**	***c***	**min**	**max**
Herring	1	0.34	2.91	0.5	0.14	0.86
Ray	1	0.34	2.91	0.5	0.14	0.86
Cod	1	0.34	2.91	0.5	0.14	0.86
Plaice	3	1.03	8.72	0.5	0.14	0.86
San ell	3	1.03	8.72	0.5	0.14	0.86
Heart urchin	6	1.73	20.77	0.5	0.11	0.89
Baltic tellin	7	2.41	20.36	0.5	0.14	0.86
Mussel bed	15	5.16	43.62	0.5	0.14	0.86
Sand gaper	15	5.16	43.62	0.5	0.14	0.86
Cockle bed	4	1.38	11.63	0.5	0.14	0.86
Iceland cyprice	50	17.19	145.42	0.5	0.14	0.86
Plumose anemone	3	0.87	8.72	0.5	0.11	0.89
Brown shrimp	2	0.69	5.82	0.5	0.14	0.86
Lobster	2	0.58	6.92	0.5	0.11	0.89
Flying crab	2	0.58	6.92	0.5	0.11	0.89
Threat worm	15	5.16	43.62	0.5	0.14	0.86
Trumpet worm	12	3.47	41.54	0.5	0.11	0.89
Zooplankton	1	0.34	2.91	0.5	0.14	0.86

3.2 Species-level impacts (condition)

Impact theme of species level impact (condition) regards the impact of

- Underwater noise disturbance
- Visual disturbance (on behaviour)

In Jak et al (2000) these impacts were noticed, but not completely worked out. Underwater noise was considered a pressure related to shipping and underwater acoustic activities. The impact of visual disturbance was more difficult to relate to a single pressure as the presence of moving or non moving objects commonly go together with noise. Therefore both pressures can cause impact. Because data were not available on single pressure-impact relations regarding visual disturbance, the effects of visual disturbance is calculated taking into account the possibility that noise can be an added value.

3.2.1 Underwater noise

In (Jak et al. 2000) no dose-response relationships of underwater noise related to ecosystem elements were established. Although negative effects of underwater noise on marine mammals are observed, no clear data were available to estimate population effects on mammals and fish. Besides negative effects, adaptation to underwater sounds is described as well.

3.2.2 Visual disturbance

Data on visual disturbance were rare at time of writing (Jak et al. 2000). The sensitivity for the presence of an object was expressed as the distance and the time that affects a species. Normally the critical reaction distance or critical escape distance is determined. The duration of disturbance is hard to estimate, and relates both to properties of the objects and the species considered.

Marine mammals

Bottlenose dolphins do not seem to be affected directly by visual disturbance, and although porpoises may be driven away from passing ships, actual impacts were not described. Porpoise behavioral effects do depend on the season. Especially when calves are present, in spring, the response is generally negative, whereas in other seasons the response is generally positive (Table 7).

Table 7 Positive (+) and negative (-) critical reaction distance (CRD) in meters to different objects for porpoise. 0 = no response

	+	0	-	CRD
Sailings yachts	50	30	20	50-100
Small ferry	30	50	20	50-100
Fishing boat	?	?	40	300
Large ferry	0	50	50	1200
Seed boat	0	0	100	200

Little quantitative data were present in Jak et al 2000 to estimate population effects to seals. Indications on increased mortality of pups, affected behavior, change in resting places and stress are described. Seals are relatively sensitive to disturbance of moving objects, especially during nursing of the pups. Non moving objects most probably have little effect. In Table 8 the disturbance distances for common seal to different objects is given, including the 95 percentile. The disturbance distance is the distance relative to the resting place at which the seal shows a first reaction to an approaching object. The relationship was described using the function for visual disturbance.

Table 8 Disturbance distances (m) for Common Seal to different objects (Jak et al 2000).

Object	Disturbance distance (m)	95 percentile
Hiker	50-600	550
Canoe	50-900	850
Rubber boat	50-1000	1000
Sailing yacht	50-1400	1000
Motor boat	100-1400	1200
Cruiser	100-500	400
Light aircraft	200-1000	1000

Although the distances at which the marine mammals are reasonably reliable, the translation of these distances to effects on reproduction and mortality is hard to make. In Jak et al 2000 the distances are translated as follows.

The exposure is expressed as the fraction of time and space of a grid that is disturbed. The magnitude of this fraction is determined by the CRD of the organism, and the duration of disturbance. The effects of a single disturbance on the decrease of available time and space to forage can be formulated:

$$c = fs * ft$$

c= magnitude of the effect of a single disturbance in a grid
fs= fraction of the space which cannot be used
ft= fraction of the time which cannot be used

The fraction fs and ft can be defined as follows:

$$fs = \frac{2 * l * CRD}{surface}$$

$$ft = \frac{1}{v * 24 * s}$$

l= length of the route of moving object, or section of the non moving object in the grid (km)
CRD= critical disturbance distance (km)
surface= surface of the total grid (km^2)
v= speed of the moving object (km/hour)
24= total hours a day at which organisms can be disturbed
s= specific recovery time, depending on object

The effect of disturbance is expressed by c, which reports the fraction of the grid that is permanently or temporarily useless to the normal behaviour of the organism. Although no direct effects to reproduction and mortality are concerned, in Jak et al 2000 a direct proportional relation is assumed (see Annex 1).

3.3 Species-level impacts (distribution, population size)

Impact theme species level impact (on distribution and population size) regard the impacts of
- Removal of target species (lethal)
- Removal of non-target species (lethal)

Removal of target species can be defined as the selective extraction of species by commercial and recreational fishing, whereas the removal of non-target species can be defined as the incidental extraction of non-target catches as well by commercial and recreational fishing.

Within Jak et al (2000) the extraction of target species is described by the effects of pelagic trawling, heavy beam trawl, and the otter trawl and twin-rig fisheries on herring, cod, plaice and rays. The extraction of non-target species is not specifically addressed as by catch of marine mammals by these types of fisheries is assumed not to be important.

It is important to understand the relation between the mortality due to fisheries, catch-ability-coefficient, the catch, the stock, and the Catch per Unit Effort (CUE) to estimate the disturbance-effect relationship regarding extraction of organisms by fisheries. These factors were all taken into account to assess the dose-response relationship.

In Table 9 the mortality per age class for herring caused by natural factors, fisheries for consumption, and fisheries for other industries is given, in Table 10 the same data for cod are presented. All data refer to the year 1994.

Table 9 Mortality per age class for herring caused by natural factors, fisheries for consumption, and fisheries for other industries (1994 data)

age	Natural mortality	Fishing for consumption	Fising for other industries
0	1	0.001	0.242
1	1	0.070	0.166
2	0.3	0.387	0.05
3	0.2	0.442	0.005
4	0.1	0.580	0.005
5	0.1	0.518	0.02
6	0.1	0.624	0.001
7	0.1	0.578	0.005
8	0.1	0.584	0.001
9	0.1	0.585	0

Table 10 Mortality per age class for cod caused by natural factors, landings and discards (1994 data)

age	Natural mortality	Mortality landings	Mortality discards
1	0.8	0.210	0.396
2	0.5	0.765	0.062
3	0.25	0.841	0.006
4	0.2	0.847	0.002
5	0.2	0.849	0.001
6	0.2	0.848	0.001
7	0.2	0.847	0
8	0.2	0.845	0
9	0.2	0.844	0
10	0.2	0.842	0
11	0.2	0.841	0
12	0.2	0.841	0

In Table 11 the estimated parameter d (hp-hours per km^2) for survival of fishes as consequence of fisheries activity is presented. The disturbance-effect relationship was described using a negative linear relationship without threshold (see Annex 1). Presented value d describes the decrease in survival at increasing hp-hours per square km.

Table 11 The estimated parameter d (hp-hours per km^2) for survival of fishes as consequence of fisheries activity

Potential exposure	Species	d
Pelagic trawling	Herring	1163
Otter trawling	Cod	39289
Otter trawling	Plaice	796812
Otter trawling	Ray	796812
Beam trawling	Cod	112817
Beam trawling	Plaice	73627
Beam trawling	Ray	73627

After applying these terms in the estimation of fishing mortality, the fraction of mortality at average fishing intensity (at all ICES grids of the DCS) and the maximum fishing intensity at the DCS are presented in Table 12.

Table 12 Fraction of mortality at average fishing intensity (all ICES grid on the DCS) and the maximum fishing intensity (DCS)

Potential exposure	Species	maximum	average
Pelagic trawling	Herring	1.00	0.19
Otter trawling	Cod	0.24	0.03
Otter trawling	Plaice	0.01	0
Otter trawling	Ray	0.01	0
Beam trawling	Cod	0.37	0.13
Beam trawling	Plaice	0.57	0.19
Beam trawling	Ray	0.57	0.19

It should be noticed that the intensities were estimated at the fishing efforts mid 90-ties. Applicability to fishing effort of the years > 2000 should be discussed. The uncertainty in the data is caused by natural variation. Annual averages are taken into account, but fishes have strong migration patterns. Spatial details within ICES grids are too large to the quantify the relationships correctly.

3.4 Habitat damage

Impact theme “habitat damage” regards the impacts of

- Siltation rate change
- Habitat structure change (abrasion and other physical damage)
- Habitat structure changes by removal of substratum (extraction)

Changes in siltation can be caused by outfalls, increased run off, dredging and disposal of dredged material. Abrasion is the impact on the seabed by e.g. commercial fishing, boating and anchoring. The extraction of substratum can cause impact due to the exploration and exploitation of living and non-living resources on seabed and subsoil.

In Jak et al (2000) habitat damage was described by the impact of fisheries and changed siltation.

3.4.1 Fisheries: trawling and impact on Benthos

Within Jak et al (2000) habitat damage is attributed to the activities of trawling (fisheries) on flatfish, but as well fisheries using trawl fishing on bivalves, shrimps and demersal fishes.

Because reference areas are lacking, the impact of trawl-fisheries is hard to estimate. Thereby, the by-catch and discard of this types of fisheries is large (up to 85%). This effect is discussed in the section "extraction of organisms". The impact on benthic organisms varies between the species, even within taxonomic groups. The impact depends largely on the life-strategy of the species.

Up to 85% of the caught invertebrates consist of Echinoderms. *Asterias* can recover quit well after replacement, but other species like sea urchins (up to 10% of the catch) are heavily damaged, and will not survive. In Table 13 till Table 17 overviews are given of the fraction morality as result of one time passage of different fishing methods. The dose-response relationship between fisheries and benthos was described using random probability (see Annex 1).

Table 13 Estimates fraction mortality (c) as result of a one time passage of a beam trawler (Jak et al 2000)

Species	**c**	**min**	**max**
Heart urchin	0.45	0.29	0.65
Baltic tellin	0.3		
Mussel	0.7		
Sand gaper	0.1		
Cockle	0.3		
Dog whelk	0.1		
Icelandic cyprine	0.1	0.06	0.49
Plumose anemone	0.5	0.25	0.75
Brown shrimp	0	0	0
Lobster	0.5		
Flying crab	0.1	0.06	0.49
Thread worm	0.2	0.09	0.66
Trumpet worm	0.1	0.06	0.49
Sugar kelp	0.5		
Channel wrack	0.5		
Sea lettuce	0.5		
Sea grass	0.7		

Table 14 Estimates fraction mortality (c) as result of a one time passage of a shrimp trawler (Jak et al 2000)

Species	c	min	max
Heart urchin	0.05		
Baltic tellin	0.01	0	0.58
Mussel	0.05	0.02	0.59
Sand gaper	0.01	0	0.58
Cockle	0.01		
Dog whelk	0.05		
Icelandic cyprine	0.01		
Brown shrimp	0.5		
Lobster	0.3		
Flying crab	0.1		
Thread worm	0.01		
Trumpet worm	0.3	0.09	0.80
Sugar kelp	0.1		
Channel wrack	0.1		
Sea lettuce	0.05	0.01	0.80
Sea grass	0.4	0.09	0.87

Table 15 Estimates fraction mortality (c) as result of a one time passage of an otter trawler (Jak et al 2000)

Species	c	min	max
Heart urchin	0.25		
Baltic tellin	0.15		
Mussel	0.3		
Sand gaper	0.05		
Cockle	0.1		
Dog whelk	0.05		
Icelandic cyprine	0.05		
Brown shrimp	0.03		
Lobster	0.2		
Flying crab	0.05		
Thread worm	0.1		
Trumpet worm	0.1		
Sugar kelp	0.2		
Channel wrack	0.25		
Sea lettuce	0.2		
Sea grass	0.3		

Table 16 Estimates fraction mortality (c) as result of a one time passage of a mussel trawler (jak et al 2000)

Species	c	min	max
Heart urchin	0.1		
Baltic tellin	0.05		
Mussel	0.6		
Sand gaper	0.05		
Cockle	0.1		
Dog whelk	0.1		
Icelandic cyprine	0.01		
Plumose anemone	0.8	0.23	0.94
Brown shrimp	0.01	0	0.72
Flying crab	0.1		
Thread worm	0.01		
Trumpet worm	0.3		
Sugar kelp	0.1		
Channel wrack	0.1		
Sea lettuce	0.1	0.01	0.87
Sea grass	0.5	0.07	0.93

Table 17 Estimates fraction mortality (c) as result of a one time passage of a cockle trawler (Jak et al 2000)

Species	c	min	max
Heart urchin	0.7		
Baltic tellin	0.3	0.13	0.70
Mussel	0.01	0	0.58
Sand gaper	0.04	0.02	0.59
Cockle	0.8		
Dog whelk	0.5		
Icelandic cyprine	0.3		
Plumose anemone	0.7		
Brown shrimp	0.05		
Lobster	0.1		
Flying crab	0.2		
Thread worm	0.5	0.18	0.82
Trumpet worm	0.5	0.18	0.82
Sugar kelp	0.1		
Channel wrack	0.7		
Sea lettuce	0.1	0.02	0.81
Sea grass	1	0.36	1

3.4.2 Changed siltation (water layer)

Suspended particles were considered to have an impact in three ways: decrease vision of visual predators, decrease of light used by primary producers, and interference with the respiratory and filter apparatus of filter feeders. The first two can be affected by the decreased visibility which can be judged by the Secchi depth in the upper layer of the water column. The third effect is caused by congestion of the organs by suspended matter. The first two effects are related to the amount of particles, the third is caused by the weight of the particles.

In Table 18 the maximum depth at which sea grass (*Zostera marina*) can exist at degrees of visibility (Jak et al 2000) is given. From these data it was calculated that the Secchi depth cannot be less then 0.5 m. Theoretically, the maximum depth at maximum visibility can be 3.3 m.

Table 18 Maximum depth at which sea grass (Zostera marina) can exist at degrees of visibility (Jak et al 2000).

Secchi depth (m)	Extinction coefficient	Estimate max depth
1.1	1.5	0.8-1.30
0.9	2.0	0.46-0.85

In Table 19 the minimum visibility at which no effect is expected (d), and the effect size (c) at one meter decrease of visibility in the upper layer is given. These data relate to decreased feeding or growth, not to mortality or survival. Parameter c has an negative value as the increase of visibility results in positive effects for organisms. The dose-response relationship was described using a positive linear relation with threshold (see Annex 1).

Table 19 Minimal visibility at which no effect is expected (d), and the effect size (c) at one meter decrease of visibility in the upper layer

reproduction	No effect			Effect size		
species	d	min	max	c	min	max
Seal	0.2	0.06	0.69	-5	-1.44	-17.31
Harbour porpoise	1	0.29	3.46	-1	-0.29	-3.46
Bottlenose dolphin	1	0.29	3.46	-1	-0.29	-3.46
Common tern	2	1.14	3.52	-0.5	-0.28	-0.88
Guillemot	2	0.69	5.82	-0.5	-0.17	-1.45
Fulmar	2	0.69	5.82	-0.5	-0.17	-1.45
Eider duck	0.2	0.07	0.58	-5	-1.72	-14.54
Herring	5	1.99	12.56	-0.2	-0.08	-0.50
Cod	5	1.72	14.54	-0.2	-0.07	-0.58
Sand eels	5	1.99	12.56	-0.2	-0.08	-0.50
Sugar kelp	2	0.58	6.92	-0.5	-0.14	-1.73
Sea lettuce	2	0.58	6.92	-0.3	-0.09	-1.04
Total algae	30	8.67	103	-0.03	-0.01	-0.01
Sea grass	3	1.36	6.62	-0.33	-0.15	-0.73

In Table 20 estimated lethal effect fractions are presented for some species as result of exceeding a suspended matter concentration of 200 mg/l in the lower water layer. The threshold value d represents the maximum number of days with no effect, and value c which represents the effect size (fraction) for each succeeding day. In Table 21 the same kind of data are given, but then for reproduction effects. The dose-response relationship was described using a negative linear relation with threshold (see Annex 1).

Table 20 Lethal effect as result of exceeding a suspended matter concentration in the lower water layer of 200 mg/l. The threshold value d represents the maximum number of days with no effect, and value c represents the effect size (fraction) for each succeeding day

reproduction		**No effect**			**Effect size**	
species	**d**	**min**	**max**	**c**	**min**	**max**
Sturgeon	30	13.56	66.21	0.1	0.05	0.20
Herring	10	4.53	22.07	0.1	0.05	0.20
Ray	20	9.06	44.14	0.1	0.05	0.20
Cod	10	4.53	22.07	0.1	0.05	0.20
Plaice	30	13.59	66.21	0.05	0.03	0.10
Sand eel	10	4.53	22.07	0.1	0.05	0.20
Heart urchin	365	145	365	0.001	0	0.003
Baltic tellin	365	165	365	0.001	0	0.003
Mussel bed	20	9.06	44.14	0.05	0.03	0.10
Sand gaper	25	11.33	55.18	0.05	0.02	0.11
Cockle bed	10	3.98	25.11	0.05	0.02	0.10
Dog whelk	50	19.91	125	0.1	0.04	0.11
Icelandic cyprine	50	19.91	125	0.1	0.04	0.13
Plumose anemone	10	2.89	34.62	0.01	0	0.25
Brown shrimp	75	21.66	259	0.1	0.03	0.25
Lobster	50	14.44	173	0.1	0.03	0.35
Flying crab	50	14.44	173	0.1	0.03	0.35
Zooplankton	5	2.84	8.81	0.1	0.06	0.18

Table 21 Reproduction effect as result of exceeding a suspended matter concentration in the lower water layer of 200 mg/l. The threshold value d represents the maximum number of days with no effect, and value c represents the effect size (fraction) for each succeeding day

reproduction	**No effect**			**Effect size**		
species	**d**	**min**	**max**	**c**	**min**	**max**
Sturgeon	365	165	365	0.001	0	0.003
Herring	0	0	0	0.05	0.02	0.11
Ray	30	13.59	66.21	0.05	0.02	0.11
Cod	0	0	0	0.05	0.02	0.11
Plaice	0	0	0	0.05	0.02	0.11
Sand eel	0	0	0	0.05	0.02	0.11
Heart urchin	5	1.99	12.56	0.1	0.04	0.25
Baltic tellin	5	2.27	11.04	0.1	0.04	0.25
Mussel bed	5	2.55	9.82	0.1	0.05	0.20
Sand gaper	5	2.27	11.04	0.1	0.05	0.22
Cockle bed	5	1.99	12.56	0.1	0.04	0.25
Dog whelk	10	3.98	25.11	0.1	0.04	0.25
Icelandic cyprine	5	1.99	12.56	0.1	0.04	0.25
Plumose anemone	5	1.44	17.31	0.1	0.03	0.35
Brown shrimp	5	1.44	17.31	0.1	0.03	0.35
Lobster	10	2.89	34.62	0.1	0.03	0.35
Flying crab	10	2.89	34.62	0.1	0.03	0.35
Zooplankton	0	0	0	0.1	0.14	0.44

3.5 Habitat loss

Impact theme “habitat loss” regard the impacts due to

- Habitat change (to another substratum)
- Habitat loss (to land)

Habitat change to another substratum can be defined by the impact of smothering (e.g. by man-made structures, disposal of dredge spoil). Habitat loss can as well be defined as sealing (e.g. by permanent constructions).

In Jak et al 2000 habitat loss was described by the disturbance of coverage by silt, and the removal of hard substrate and gravel.

3.5.1 Coverage with silt

In Jak et al 2000, the effects of coverage are estimates as the effects of a one time coverage with sand or silt of at least 20 cm thickness (Table 22), reflecting the deposition of disposed dredged material. No maximum thickness is defined. The magnitude of the effect depends on the thickness of the layer, the composition, the ability to grow or to move out of the layer, and the persistence to oxygen depletion (and accompanied sulphide concentrations). At the longer term decolonisation is important. The importance of seasonality is not clear (Jak et al 2000). The effects of coverage with sand or silt can vary strongly as the fine organic rich silt can go together with oxygen depletion. Besides that, other parameters as temperature and availability of oxygen and the life stage of the organisms are important. The relationship between coverage and mortality was described using a homogenic probabilistic function (see Annex 1).

Table 22 Lethal effects (c) with minimum and maximum of one time coverage with a layer of at least 20 cm sand or silt.

Species	c (mortality)	min	max
Heart urchin	0.9	0.39	0.96
Baltic tellin	0.5	0.21	0.79
Mussel bed	1.0	0.36	1.00
Sand gaper	0.8	0.51	0.87
Cockle bed	1.0	0.43	1.00
Dog whelk	1.0	0.36	1.00
Icelandic cyprine	0.9	0.45	0.95
Plumose anemone	1.0	0.36	1.00
Brown shrimp	0.2	0.07	0.71
Lobster	1.0	0.36	1.00
Flying crab	0.1	0.04	0.68
Thread worm	0.2	0.07	0.71
Trumpet worm	0.9	0.32	0.96
Sugar kelp	1.0	0..36	1.00
Sea lettuce	1.0	0.36	1.00
Sea grass	1.0	0.36	1.00
Meadow	1.0	0.36	1.00

3.5.2 Removal of hard substrates and gravel

Hard substrate is of value for species which attach themselves to it. When these substrates are removed by e.g mining these species will be lost. The relationship between removal of substrate and mortality was described using a homogenic probabilistic function (see Annex 1). All parameter values are set to 1, assuming total mortality as result of removal of hard substrate (Table 23).

Table 23 Fraction mortality c, as result of removal of hard substrate

Species	mortality *c*
Mussel bed	1
Dog whelk	1
Plumose anemone	1
Lobster	1
Sugar kelp	1
Channel wrack	1
Sea lettuce	1

The removal of gravel has a direct impact on local organisms like benthic organisms as lobsters and plumose anemone. But as well fishes that depend on the ecosystem characteristics of gravel for spawning grounds may be affected.

Table 24 Fraction mortality c, as result of removal of gravel

Species	mortality *c*	min	max
Plumose anemone	1	0.43	1
Lobster	1	0.36	1
Reproduction			
Herring	0	0	0.71

4 References

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Justification

Rapport C011/09

The scientific quality of this report has been peer reviewed by the a colleague scientist and the head of the department of Wageningen IMARES.

Approved: Dr. R.G. Jak
Marine Ecologist

Signature:

Date: February 2, 2009

Approved: J.H.M. Schobben MSc.
Head of the Department of Environment

Signature:

Date: February 2, 2009

Annex 1 Disturbance-Effect Relationship types

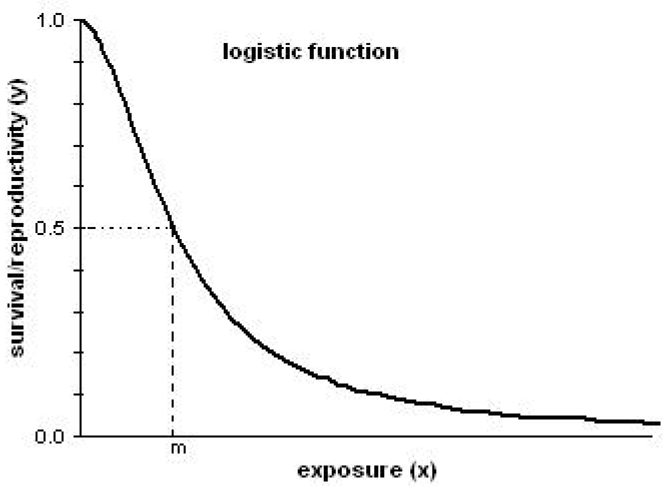
The different functions are described and visualized below. As much as possible generic parameters were used, which all have the same representation in all functions:

m	=	median intensity of effect, disturbance at which the effect = 50%
d	=	threshold, disturbance intensity at which effect will occur
c	=	intensity-effect coefficient, which describes the slope f the function

De variables in the equations are described by y as the effect on survival/ reproduction (fraction between 0 en 1) and x as the disturbance intensity of the potential exposure.

1. Logistic function

$$y = \frac{1}{1 + \left(\frac{x}{m}\right)^{c}}$$

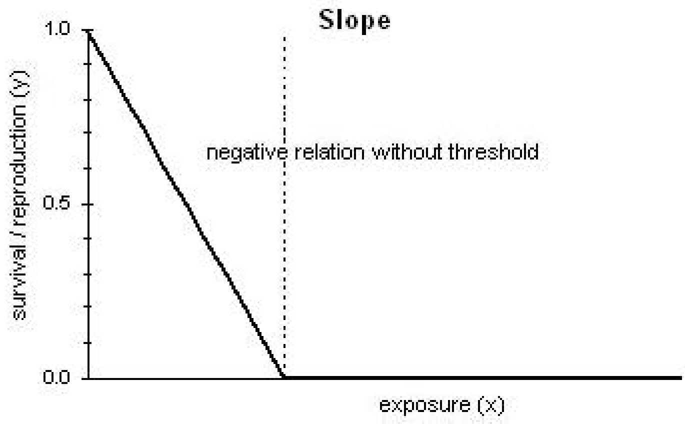


2. Negative linear relation without threshold

d is the intensity of the potential expose (e.g. hp-hours) at which survival is 0.

$$x < d \Rightarrow y = 1 - \frac{x}{d}$$

$$x \geq d \Rightarrow y = 0$$

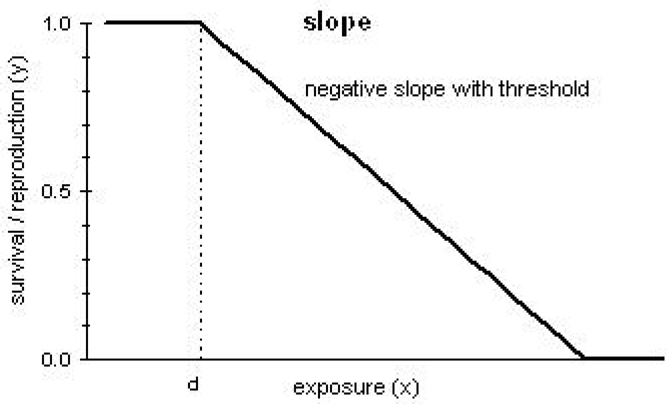


3. Negative linear relation with threshold

$$x \leq d \Rightarrow y = 1$$

$$d < x < \left(d + \left(\frac{1}{c} \right) \right) \Rightarrow y = (1 - c(x - d))$$

$$x \geq \left(d + \left(\frac{1}{c} \right) \right) \Rightarrow y = 0$$



Parameter d indicates the threshold, parameter c (always a positive value) the slope.

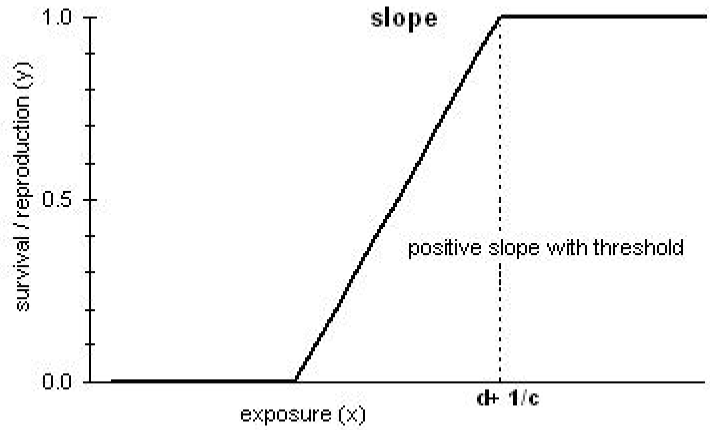
4. Positive linear relation with threshold

$$x \leq d \Rightarrow y = 1$$

$$d < x < \left(d + \left(\frac{1}{c} \right) \right)$$

$$x \geq \left(d + \left(\frac{1}{c} \right) \right) \Rightarrow$$

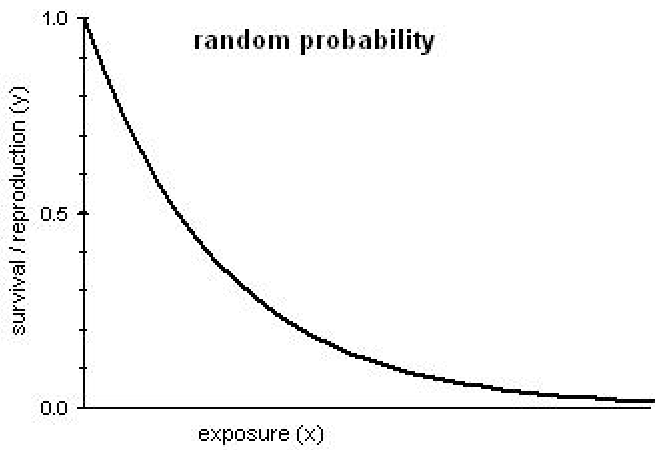
Parameter d indicates the threshold, parameter c (always a positive value) the slope.



5. Random probability function

$$y = 1 - \sum_{i=0}^{i=12} \left(\left(\frac{x^i e^{-x}}{i!} \right) * (1-c)^i \right)$$

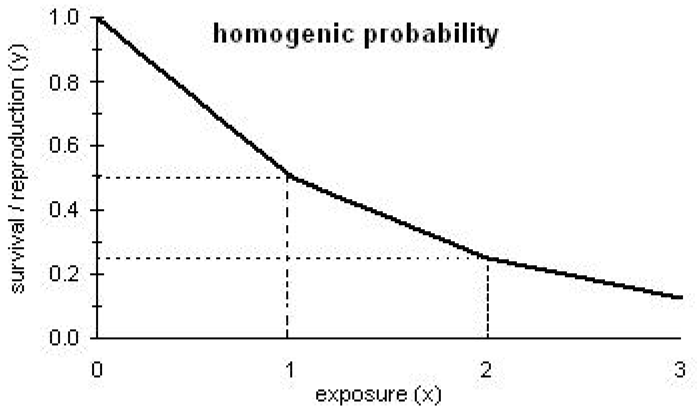
Parameter c presents mortality (e.g. after one time passing of a beam trawler). e is the base of the natural logarithm (2.72). i is an index from 0 - 12.



6. Homogenic probability function

$$y = (1 - xMOD1)c^{xDIV1} + (xMOD1)c^{(xDIV1+1)}$$

Parameter c. presents mortality (e.g. after one time removal of substrate). y en x present respectively the fraction survival or reproduction and intensity of exposure. MOD represents the residue of the division (14.4 MOD 4 e.g. equals 2.4), and DIV represents the total part after a division (14.4 DIV 4 equals e.g. 3).



7. Visual disturbance function

Parameter c represents the time to return (time after which a bird or mammal return after disturbance in the disturbed area) Parameter d is the critical disturbance distance, e is the base of the natural logarithm (2.72), y is fraction undisturbed reproduction and x represents the potential exposure (number of hours present in an area multiplied with speed)