Report of the second meeting of the study committee:

Trawling: finding common ground on the scientific knowledge regarding best practices

Held 24-26 November 2013 IJmuiden Netherlands

The meeting was held 24-26 November 2013. Attending the meeting were Ricardo Amoroso, Jeremy Collie, Daniel van Denderen, Jan Hiddink, Ray Hilborn, Kathryn Hughes, Simon Jennings, Michel Kaiser, Tobias van Kooten, Bob McConnaughey, Ana Parma, Roland Pitcher, Adriaan Rijnsdorp and Petri Suuronen.

The agenda of the meeting is attached as Appendix I.

REPORT ON STAKEHOLDER CONSULTATION

Stakeholder consultation has taken two forms. We have held one-on-one discussions with a number of stakeholders, with particular input from WWF, MSC and some industry groups. We have also instituted a more formal consultative process described below.

The aims of stakeholder consultation were:

1. Identify priority research questions that, if answered, would provide evidence to inform behavioural, policy or management change in towed bottom contact gear fisheries
2. Provide a short-list of questions which will provide a useful tool for funders of science to focus their attention on areas where the impact of new information will be greatest.

The research question prioritisation exercise generated a total of 108 separate questions. The stakeholder group voted on the priority they attached to each question and the results were used to rank the questions in order of priority within each of four categories. The ranked questions were then assessed in relation to the extent to which they were addressed by the present study. Table 1 presents those questions identified by the stakeholder group that can be answered by the current project. The remaining questions are valuable in the context of providing a focus for future research funding. We plan to further prioritise future research questions with stakeholders through a series of webinars. The webinar prioritisation exercise will provide a consensus approach to eliminate duplicate questions and refine them. The prioritization exercise may lead to a policy orientated publication. We will use the highest priority questions to guide the outputs we generate from the project to ensure the outputs address the most urgent stakeholder needs.

Table 1. The short-listed questions from the stakeholder prioritisation exercise. These questions received the highest number of votes and were considered to be answerable by the current project, but do not include other important questions identified by the stakeholder group that fell outside the scope of the current project. The questions are listed in rank order of priority based on voting. Some wording was removed from the original questions for clarity or to bring the question within the remit of the current research programme. The removed wording is preserved in the original spreadsheet to maintain a full audit of question development.

Question #	**Ecosystem productivity**
71	What are the risks of trawling to various components of the ecosystem? What research can give some confidence around understanding of the risks and nature of impacts on seabed communities from trawl fishing?
83	Once an area has had a history of being trawled (inside the trawl footprint as known fishing grounds), what ongoing ecosystem damage is occurring by continuing to trawl in this area? Does this include changes in composition. What is the best way to measure trawling over a certain area (number of tows, hours, etc)?
25	What are the “best practices” for trawling in order to minimize impacts on other habitat?
90	Specifically, what are the impacts of fish trawling on the benthos?

	Direct effects
86	How does the intensity of trawling by different trawl methods affect different habitats?
105	What changes are made to a specific type of bottom i.e. coral, mud gravel etc. by repeated bottom trawling?
62	How do different types of seabed habitats differ in their susceptibility to impacts from towed gear and their ability to recover after such impacts?
91	Is physical damage to habitats caused by trawling irreversible. What is required to test for reversibility or recovery?
39	How does trawling affect macro-faunal (both sessile and mobile) invertebrate communities and how resilient are these invertebrate communities to varying levels or intensities of trawl effort?
64	To what extent are the impacts of towed fishing gear mediated by variation in habitat susceptibility, in species recovery rates and in spatial overlaps between distribution of fishing effort intensity and the distribution of habitats?

17	What aspects of towing a mobile bottom-tending gear (e.g., tow length and time, tow path, speed, etc.) causes the most disturbance to particular habitat types? Does the relative impact differ by habitat type?
96	What specific effect does twin rigging have on the various seabed types?
106	Are these changes [to habitat by repeated trawling] reversible?

Operational

61	How do different types of bottom fishing gear differ in their interactions with the seabed?
84	What level of damage occurs from using different net and ground gear designs for each habitat type (as classified under the habitat and communities ERA framework)? Will this need to look at different combinations of gear?

Management indicators

10	How can benthic impacts be managed and mitigated?
5	Lasting impact of trawling on 'vulnerable marine ecosystems' (*sensu* FAO Guidelines) occurred and may still happen. What are the more efficient mitigation measures? (e.g. area closures, technical measures, overall effort reductions, etc.)?
7	What sort of mitigation measures are in line with best practices? What examples are available for each measure?
44	What are the relative benefits of spatial management to constrain the trawl fleet footprint versus trawl effort controls or both? (ie. Should a lower intensity of trawl effort be spread out over a larger area of trawl grounds or should trawl effort be concentrated into a smaller footprint, but perhaps a higher intensity of trawling per unit area?
79	To what extent is understanding and management assisted by understanding what/where/how much habitats are untrawlable at a variety of scales. Should such areas be considered (along with closures) in making environmental assessments of trawling. To what extent do better maps of habitat, improved navigational technology, and changing fishing practices (eg. increased risk taking when market prices are high) contribute to determining trawlable and untrawlable bottom.
11	How best can the status and outcome of benthic impacts be measured? What best practices exist?
65	To what extent is the identification of best practice management measures contingent upon differences in management objectives and the values that are sought to be maintained?

PHASE I: EXTENT OF TRAWLING

With inputs from many agencies we have compiled the most extensive high resolution picture of trawling activity on the world's continental shelves. We are continuing to seek more data to develop this picture, with a particular focus on Africa, Asia and South America. For the same areas we are compiling information on seabed habitats to link the footprint of trawling to the distribution of habitat. These layers will underpin the Phase 3 analysis on the interactions between trawling and the environment, where we assess the positive and negative consequences of existing practices. The map (Figure 1) shows where we now have data sets (yellow pins) and where we have inquiries that we hope will lead to further data sets. Further information on these data sets is provided in Table 2.

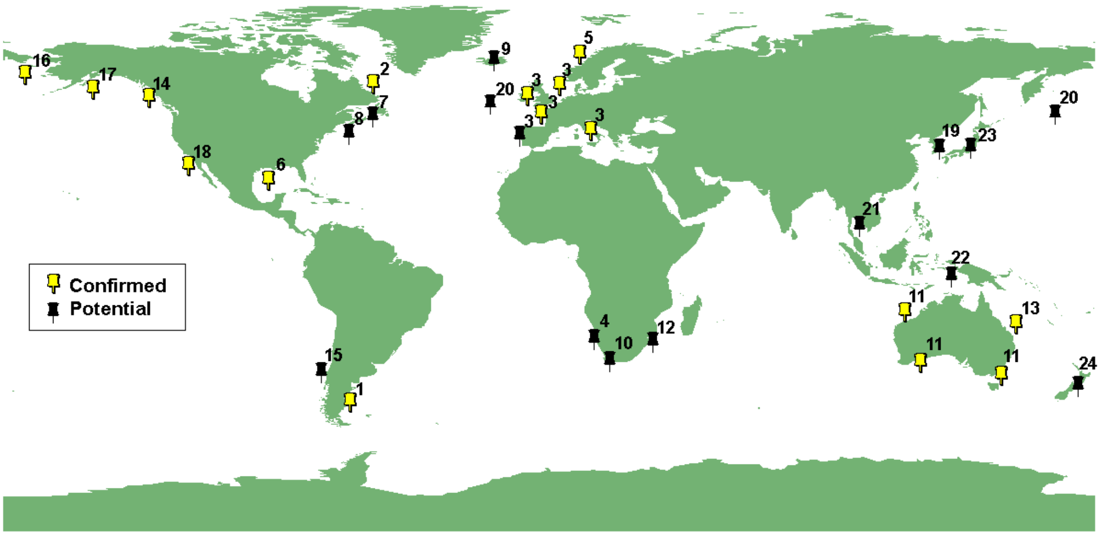


Figure 1. Location of data sets on trawl activity and distribution. Numbers defined in Table 2.

Table 2. Status of fishing effort compilations. (TBD: to be determined, VMS: data from a satellite Vessel Monitoring System).

Ocean	Map code	FAO area	Nation	Region	Expected format	Status
Atlantic Ocean	1	41	Argentina	Patagonian shelf	VMS	available and commitment to collaborate
Atlantic Ocean	2	21	Canada	East coast	Aggregated individual tows	In hand and analyzing
Atlantic Ocean	3	27	Europe	European EEZ	VMS (collation by EU 'BENTHIS' project)	available and commitment to collaborate
Atlantic Ocean	4	47	Namibia	Namibian EEZ	VMS	potential - data exist and discussions ongoing
Atlantic Ocean	5	27	Norway	Norwegian Sea/ Barents Sea	VMS (collation by EU 'BENTHIS' project)	available and commitment to collaborate
Atlantic Ocean	6	31	United States	Gulf of Mexico	Aggregated effort	available and commitment to collaborate
Atlantic Ocean	7	21	United States	Scotian shelf	VMS	available and commitment to collaborate
Atlantic Ocean	8	21	United States	Georges Bank	VMS	available and commitment to collaborate
Atlantic Ocean	9	27	Iceland	Icelandic shelf	Aggregated individual tows	potential - data exist and discussions ongoing
Atlantic Ocean	10	47	South Africa	West and south coast	VMS	potential - data exist and discussions ongoing
Indian Ocean	11	57	Australia	NW, W and S coasts	VMS	available and commitment to collaborate
Indian Ocean	12	47, 51	South Africa	East Coast	TBD	potential - data exist and discussions ongoing

Ocean	Map code	FAO area	Nation	Region	Expected format	Status
Pacific Ocean	13	71, 81	Australia	East Coast	VMS	available and commitment to collaborate
Pacific Ocean	14	67	Canada	West Coast	VMS	available and commitment to collaborate
Pacific Ocean	15	87	Chile	Chilean EEZ	VMS	in hand and analyzing
Pacific Ocean	16	67	United States	Bering Sea	Aggregated individual tows	in hand and analyzing
Pacific Ocean	17	67	United States	Gulf of Alaska and Aleutian Islands	Aggregated individual tows	in hand and analyzing
Pacific Ocean	18	77	United States	West Coast	Aggregated individual tows	in hand and analyzing
Pacific Ocean	19	61	South Korea	EEZ	TBD	potential - data exist and discussions ongoing
Global	20	27 & 77	Russia	Northeast Atlantic and Northwest Pacific	TBD	potential - data exist and discussions ongoing
Indian Ocean	21	71	Thailand	Gulf of Thailand	TBD	potential - data exist and discussions ongoing
Indian Ocean	22	71	Indonesia	Indonesian Fishery	TBD	potential - data exist and discussions ongoing
Pacific Ocean	23	61	Japan	Japanese EEZ	Total effort over time	potential - data exist and discussions ongoing
Pacific Ocean	24	81	New Zealand	New Zealand EEZ	VMS	available and commitment to collaborate

PHASE II: IMPACTS OF TRAWLING ON BENTHIC BIOTA AND HABITATS

The second phase will compile and evaluate the impact of mobile bottom fishing on the abundance and diversity of biota, looking especially at the key factors of intensity of trawling, gear type and type of habitat trawled. Given the great interest in the subject and criticisms of previous reviews (Collie et al. 2000; Kaiser et al. 2006) that there was bias in the choice of studies included, the committee felt that a very thorough and transparent process be used to identify studies for the data synthesis. Thus the internationally recognized “systematic review” has been applied using the collaboration for environmental evidence (CEE) guidelines, although it is a time consuming process. The approach of using systematic reviews in ecology and conservation is a relatively recent development and has its roots in the medical sciences. It is considered the most robust approach to reviewing the literature from which meta-data are compiled. It implicitly eliminates the risk of bias and is a transparent and repeatable methodology.

The systematic review protocol has been reviewed by all of the trawl committee members as well as stakeholders involved in the project and is now ready to be submitted for peer review in the open access journal "Environmental Evidence". The current bibliography includes >25,000 references. The total number of article titles to be read are estimated (based on expert knowledge) at 30,000-35,000. A sensitivity analysis in which 100 random articles were taken from the bibliography showed that 3% of articles are likely to be found relevant for further examination based on the wording of their title. Thus there is a high 'discard' rate: 97% of all articles are predicted to be excluded from the review based on reading the title alone. Therefore, accepting the higher estimate of the final bibliography (35,000 articles), about 1050 articles are likely to be read to at least abstract level. In total there are 24 computerized databases, 3 websites and 26 specialist sources that will be searched for information - giving a global representation of primary and grey literature. Current aims include completion of searches by the end of January 2014 and the completion of all data extraction for the meta-analysis by the end of April 2014.

PHASE III: RISK ANALYSIS

Phase III will conduct a risk analysis of the impacts of trawling on alternative habitats, regions and fisheries. Roland Pitcher presented a worked example for a single Australian trawl fishery. Because this example used confidential data we are not able to share it in the meeting report but Roland has prepared a mock example given as Appendix II in this report that does not use any confidential data.

The risk analysis has the following inputs

1. The spatial map of intensity of trawl effort from Phase I
2. The spatial map of substrates from Phase I
3. The impact of one pass of a trawl on different biota in each substrate type from Phase II
4. The recovery rates for different biota from Phase II

The data from items 1 and 2 are then used to produce a table that summarizes the “trawl footprint”, i.e. the area in each substrate type by intensity of trawl effort. Below is a sample of what that data might look like for a particular region.

# of times Trawled per year	Total Area	Area of Gravel	Area of Mud	Area of MudSand	Area of Sand
0	1782	664	30	213	875
0.01	236	61	4	47	124
0.015	75	22	1	13	39
0.03	85	19	3	22	41
0.06	110	23	1	28	58
0.125	133	23	2	50	58
0.25	193	31	na	69	83
0.5	194	36	2	37	119
1	268	44	5	87	132
2	189	46	na	37	106
4	77	24	na	7	46

We will combine the estimates of the area subject to different intensities of trawl effort with the impact rate of trawling on biota (input 3) and recovery rates (input 4), in a dynamic model similar to those used for fisheries stock assessments, to estimate the expected long-term impact on each taxon in each substrate type. Initially, this will be a relative assessment aggregated across all fauna for each habitat, at the widest possible spatial scale. The relative status of habitats can be mapped and also summarized in table form. Below is a sample of what that data might look like (as percentages) for habitats in a particular region.

# of times Trawled per year	Relative status in Gravel	Relative status in Mud	Relative status in MudSand	Relative status in Sand
0	100	100	100	100
0.01	100	100	100	100
0.015	99	99	100	100
0.03	99	99	99	100
0.06	98	98	98	100
0.125	95	95	97	99
0.25	90	na	94	98
0.5	80	80	87	97
1	61	71	74	93
2	24	na	48	88
4	0	na	27	72
Average status	**91**	**96**	**90**	**98**

Subsequently, if we are able to obtain data on the distribution of biota by substrate type we can calculate the actual total reduction of abundance in each taxon, integrated across substrate types. It is likely that this more detailed analysis is possible only for regional case studies where suitable data are available.

Appendix II provides the completely worked example.

PHASE IV: IMPACTS ON TARGET FISH STOCKS

Phase IV will look at the medium-term and long-term impact of trawling on the productivity and sustainable yield of different target species relative to the effect of fishing. After a preliminary literature review presented during the meeting it was showed that the existing studies are fragmentary and thus a meta-analysis is not possible. Therefore, a structured review of empirical and modeling studies will be carried out around three axes that were identified as the main ways in which trawling can affect the productivity of the target species:

(i) Trawling impacts on the habitat of the target species
(ii) Trawling impacts on the predators of target species
(iii) Trawling impacts on the prey of target species

The structured review will lead to a summary of current knowledge and recommendations about a research agenda that is required to address question on the trawling impact on fish productivity.

The work plan has been discussed and specific tasks have been allocated. A 1st draft of the review paper will be available at the next meeting (September 2014).

PHASE V: EVALUATE ALTERNATIVE BEST PRACTICES

Phase V will identify and test a range of management options and industry practices that may improve the environmental performance of trawl fisheries; with a view to defining ‘best practice’. For each option or practice, the impact on biota, sustainable food production, ecosystems and ecosystem services will be evaluated, along with changes in fuel consumption and other costs and impacts.

Group discussions and research have identified a range of practices and options that are intended to promote sustainable harvesting with trawls (Table 3). The options range from traditional conservation tools, such as area closures, to more innovative approaches that are designed to limit specific impacts. A set of performance metrics is also being developed to compare and contrast the efficacy of the different approaches in an evidence-based analytical framework that links to outcomes from the preceding phases of the project. For example, the Phase III risk analysis provides a basis for considering probable responses to trawl-gear modifications that are designed to minimize contact with the seafloor and reduce the removal of benthic biota, while Phase IV methodology supports interpretation of the corresponding changes in impacts on targeted fish populations. Similarly, the effects of closures that redirect effort to other habitat types can be considered based on understandings of habitat-specific impact relationships resulting from Phases I and II. New committee work will concentrate on the methodology for incorporating this information into the best-practices analysis.

A summary of trawl-fishery activities and management in Southeast Asia was presented during the meeting and reinforced the need to provide best-practice guidance that is adaptable to diverse local circumstances, as opposed to more specific prescriptive recommendations. It was agreed that a broad range of trawl fisheries should be the studied and that it would be advantageous to confer with local experts in representative areas.

Table 3. Status of the analytical framework for an evidence-based review of impacts associated with management options and industry practices for reducing trawling effects on seafloor habitat. Impact metrics will be a basis for evaluating performance of the different approaches.

Option/Impact[1]	**Benthic biota**	**Sustainable fish populations / food production**	**Ecosystems and ecosystem services**	**Fleet performance**	**Comments**
Freeze fishing footprint					Limit future trawling to previously trawled areas.
Prohibitions by gear type					Trawls cannot be used in designated geographic areas (permanent, seasonal, rotational, or bycatch activated).
Prohibitions by habitat class					Trawls cannot be used in designated habitats.
Gear modifications					Specific configurations required to reduce impacts.
Invertebrate bycatch quota					Restrictive management measures to limit aggregate catch of designated benthic invertebrate(s).
Habitat impact quotas					Gear- and habitat-specific “cap-and-trade” system for effort (theoretical).
Broad-scale habitat management					Multi-purpose habitat-conservation programs (*e.g.*, MPA, EFH, HAPC).
Removal of effort					Fleet reductions through buybacks, licensing, etc.
Others TBD					From continued stakeholder inputs

[1] Impact metrics (preliminary)

- Benthic biota – biomass*, diversity/richness, abundance (problematic for colonial organisms), species composition (difficult interpretation), size spectra (useful but laborious).
- Sustainable fish populations / food production, Ecosystems and ecosystem services – TBD after consultations with stakeholders and subject-matter experts.
- Fleet performance – direct costs (including those related to gear change/modification, fuel usage, production rates/efficiency); others TBD after consultations with stakeholders and subject-matter experts.

OTHER BUSINESS: NEXT MEETING TIME AND VENUE

Petri Suuronen from FAO provided an overview on the trawl fisheries of S.E. Asia, which are some of the largest and most intense in the world. At present we do not have any data sets from this region, but with the assistance of funding from FAO we have scheduled our next meeting to be in S.E. Asia (likely Bangkok) from 8-12 September. This meeting will combine a 3 day meeting of our group with a 2 day meeting with regional experts.

APPENDIX I

Agenda for second meeting of Trawl Committee

Sunday 24 November IMARES (IJmuiden) Netherlands
Haringkade 1
1976 CP IJmuiden
The Netherlands

9:00 Welcome and comments on progress (Ray, Mike, Simon)

Introductions:

Upate on feedback with stakeholders (Mike)

Current Status Phase I – extent of trawling and habitats (Simon, Ricky)

Coffee Break

Current Status Phase II –impacts on biota (Mike, Cathryn)

Lunch

Presentation by Daniel van Denderen and Tobias van Kooten from their work relevant to a range of Phases.

Coffee

Current Status and thoughts Phase IV – impacts of productivity and broader ecosystem (Adriaan Jeremy, Ricky)

Current Status and thoughts Phase V – alternative best practices (Bob)

Presentation by Petri Suuronen on FAO work and proposed best practices

Monday 25 November

Current Status and thoughts Phase III – risk analysis (Roland)

Review of data sets: current and potential applied to all phases.

Rest of day spent in individual groups working on specific tasks

Tuesday 26 November

Report back from each group

Identification of further data sets and people to contact

Assignment of responsibilities before next meeting

Plan for next meeting/ time and place.

APPENDIX II

Trawl Risk Assessment 'mock-up' example for a fictitious trawl fishery

This example risk assessment is intended to represent the procedure that Phase 3 of the Project anticipates using to estimate the status of unconsolidated shelf seabed habitats, based on outputs from Phase 1 including maps of trawl effort and maps of seabed sediment class type, and outputs from the Phase 2 meta-analysis including estimates of trawl impact and recovery rates for a range of gear types, habitat types and faunal types.

This example is based on a fictitious fishery, using otter trawl gear in a large bay of area ~4,000 km² including depths >1 to 50m. Trawl effort is represented in a similar manner as is currently being collated by the Project; i.e. total annual effort calculated as total swept-area ratio of 0.01° grid cells (~1x1 km). A sediment class map and some faunal distributions were also represented for the fictitious area. For the purpose of this example, several assumptions have been made regarding previously published impact and recovery information. It is anticipated that the updated meta-analysis from Phase 2 will avoid these assumptions.

It is expected that the risk assessment will be based on the logistic population growth model with an additional term for trawl effects: $\delta B/\delta t = rB(1-B/K) - dFB$ where B is the abundance, t is time, r is population growth rate, K is carrying capacity, d is trawl depletion rate and F is trawling effort.

1. Meta-analysis results

The meta-analysis results of Collie et al. (2000) were used as input for this example, although Kaiser et al (2006) captures more studies and provides more detail — including in the appendices. The main factor effects were taken from Fig. 2 in Collie et al. and recovery times from Fig.5 (see Appendix III) and ignored the possibility of interactions for this example.

The impact values (i) were as follows: Grand mean response (Log_e) = -0.79

Gear main effect		*Substratum main effect*	
intertidal dredging	-1.9	Gravel	-0.98
scallop dredging	-1.1	muddySand	-0.84
intertidal raking	-1.7	Biogenic	-0.82
beam trawling	-0.55	Sand	-0.78
otter trawling	-0.47	Mud	-0.62

		Inferred taxa effects for otter trawling				
Taxa main effect		*Gravel*	*muddySand*	*Biogenic*	*Sand*	*Mud*
Anthozoa	-1.36	-1.23	-1.09	-1.07	-1.03	-0.87
Malacostraca	-1.35	-1.22	-1.08	-1.06	-1.02	-0.86
Ophiuroidea	-0.89	-0.76	-0.62	-0.6	-0.56	-0.40
Holothuroidea	-0.84	-0.71	-0.57	-0.55	-0.51	-0.35
Maxillopoda	-0.8	-0.67	-0.53	-0.51	-0.47	-0.31
Polychaeta	-0.8	-0.67	-0.53	-0.51	-0.47	-0.31
Gastropoda	-0.75	-0.62	-0.48	-0.46	-0.42	-0.26
Echinoidea	-0.7	-0.57	-0.43	-0.41	-0.37	-0.21
Bivalvia	-0.5	-0.37	-0.23	-0.21	-0.17	-0.01
Desmospongia	-0.48	-0.35	-0.21	-0.19	-0.15	0.01
Asteroidea	-0.29	-0.16	-0.02	0.00	0.04	0.20
Oligochaeta	-0.24	-0.11	0.03	0.05	0.09	0.25

These impact values were assumed to represent the effect of single trawls, although this was not specified and may not have been the case for all studies contributing to the meta-analysis. Thus, later calculations used per-trawl depletion rate as $d = 1\text{-exp}(i)$; i.e. an impact rate of -1 corresponds to a depletion of 63.2%.

The recovery times across 3 gear types, 4 habitat types and 3 faunal taxa ranged from about <100 to ~400 days (Fig.5 in Appendix). There appeared to be some difference in recovery rates across habitat (sediment) types (for all fauna classes pooled), with about 2 months on Sand, about 6 months on Mud, ~9 months on muddySand. Gravel was not presented, but was assumed as about 500 days or 18 months given the Project discussions suggesting faunal types on gravel substrates recover more slowly.

Recovery times (Fig.5 in Appendix) differed to some extent among the 3 taxa presented (for all substrata pooled), with about 4 months for Polychaeta, ~10 months for Malacostraca, and ~16 months for Bivalvia. The recovery information was available for main effects only — and again, for the present purposes, the possibility of interactions and unbalanced source data were ignored to infer taxa-by-substratum recovery times, as tabulated below (in days). Ultimately, the Phase 2 meta-analysis is expected to provide sufficient evidence to differentiate these recovery rates.

Substratum	All fauna	Polychaeta	Malacostraca	Bivalvia
All substrata	-	120	300	480
Sand	60	30	75	119
mud	200	94	236	377
mudSand	250	119	297	475
Gravel	500	237	593	948

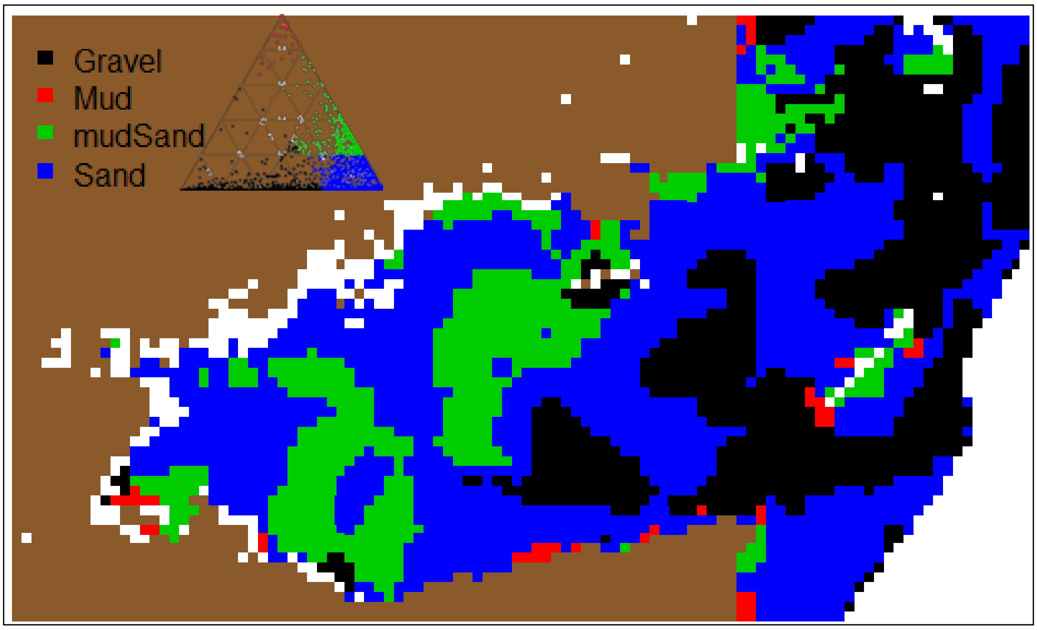
To estimate the logistic *r* parameter, the logistic equation was solved for *r* corresponding to a recovered abundance of 95% of *K*, after times as tabulated above, following a single impact of magnitude as tabulated for otter trawling above — for 3 faunal taxa in 4 substratum categories. This will provide some differentiation among taxa groups and habitats in this example.

2. Substratum

Sediment data are often available as continuous %mud, %sand, %gravel, so will be converted to categories matching those used in the meta-analyses. Categories in the previous meta-analyses included: Gravel, Sand, Mud, muddySand. These do not conform to a full sediment ternary distribution, so a modified conversion was used:

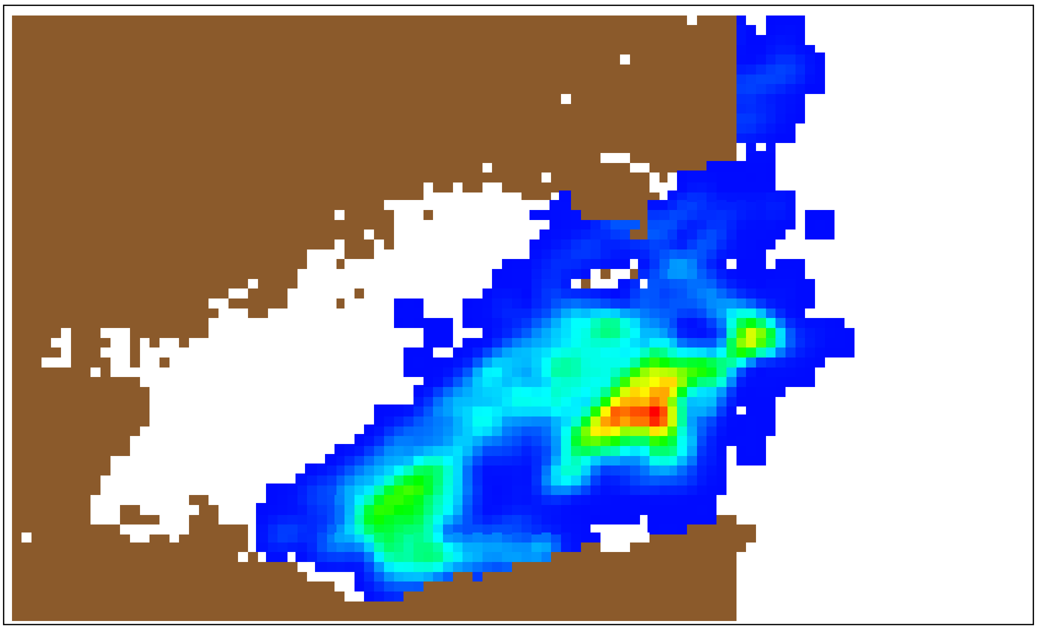
Gravel=gravel>30%, else Sand=mud<20%, else Mud=sand<20%, else =muddySand

Sediment category distribution map:



3. Trawl effort & trawled area

The project plans to conduct analyses using trawl effort data at 1 km / 0.01° resolution wherever possible, as at this scale trawling is expected to be randomly distributed. The map below shows effort for the fictitious fishery as average annual swept-area ratio for 0.01° cells (blue=low; red=high). Ultimately, confidentiality requirements may limit presentation to coarser grid resolutions and thresholds for cells where few vessels have trawled, even though analysis will be conducted without these limitations where possible.



The area trawled was estimated using both uniform and random scenarios for within grid trawling, and summarized in base-2 swept-cover categories as tabulated below. Most of the fictitious bay is not trawled at all, most 'trawl grounds' are trawled less than once per year, and only a small area is heavily trawled; the heaviest 0.01° cell-scale coverage was ~7.8 times/yr.

Cover category	Grid count	Gravel	Mud	mudSand	Sand	Area km²	Swept km²	Uniform km²	Poisson km²
0	1782	664	30	213	875	2042	0	0	0
>0-0.0078125	236	61	4	47	124	270	2	2	2
0.015625	75	22	1	13	39	86	2	2	2
0.03125	85	19	3	22	41	97	4	4	4
0.0625	110	23	1	28	58	126	11	11	11
0.125	133	23	2	50	58	152	28	28	25
0.25	183	31	0	69	83	210	74	74	62
0.5	194	36	2	37	119	222	160	160	113
1	268	44	5	87	132	307	451	307	233
2	189	46	0	37	106	216	590	216	200
4	77	24	0	7	46	88	481	88	88
Totals	**3,332**	**993**	**48**	**610**	**1,681**	**3817**	**1803**	**892**	**740**

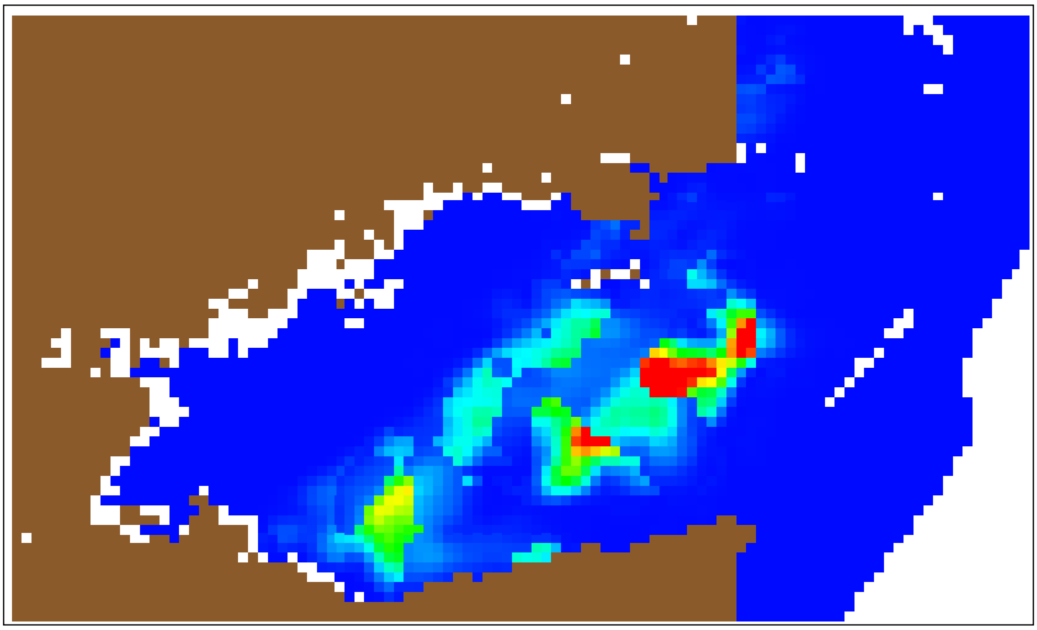
Trawling is rarely if ever conducted uniformly, but has some degree of randomness or aggregation at fine scales. The random (Poisson) scenario is indicative of area trawled in a single year. However, because within cell aggregation is (with some possible exceptions) generally not fixed in space the long run expectation is that every gear-scale 'pixel' within a 0.01° grid-cell is ultimately trawled at the average cover rate. Hence, the uniform scenario is more representative of the multi-year trawl footprint.

4. “Risk assessment” for habitats

The first level of risk assessment is for habitat types (sediment categories), for which impact and recovery rates were available from Collie et al (2000). By inference, the status of these habitats represents an average over the mix of benthic fauna present in these sediments categories across the range of studies contributing to the meta-analysis. In this example, the ‘pristine’ status of each habitat/grid cell was set to unity initially and the assessment involved estimating the relative equilibrium population status for each grid cell, assuming the grid effort in section 3 has been applied indefinitely, as 1-*F.d/r* (which is appropriate for random trawling within cells) where *F* is in units of swept covers. The expected status of each habitat type is summarized in the table below, for untrawled areas, for trawled area in base-2 swept-cover categories and by habitat type:

	Summary results for Habitat			
Cover category	Gravel	Mud	mudSand	Sand
0	1	1	1	1
>0-0.0078125	1.000	1.000	1.000	1.000
0.015625	0.994	0.993	0.996	0.999
0.03125	0.987	0.989	0.992	0.998
0.0625	0.977	0.980	0.984	0.996
0.125	0.952	0.948	0.968	0.992
0.25	0.899		0.940	0.983
0.5	0.799	0.800	0.872	0.966
1	0.609	0.714	0.743	0.929
2	0.237		0.480	0.877
4	0.000		0.270	0.723
Overall avg state:	0.911	0.958	0.905	0.975
Avg state in trawled cells:	0.730	0.889	0.854	0.949

The gravel habitat was estimated to be affected most at almost all levels of effort, due to higher impact rates and slower recovery rates — at swept-covers >4x the gravel habitat was estimated to be fully depleted. However, the bay-wide status of mudSand was slightly lower overall because this habitat was relatively more exposed to the distribution of effort. A map of relative impact status of habitats for 0.01° cells is presented below; note that because relative status was used, any map of status will strongly reflect the pattern of effort — with a subtle overlay due to impact-recovery differences among sediment types. The colour ramp represents ‘pristine’ status 1=blue to fully impacted status 0=red.



The habitat risk assessment is likely to the level most widely achievable, in geographic terms, by the Project. In some cases, depending on data availability, it may be possible to also provide relative risk assessments for some individual faunal groups.

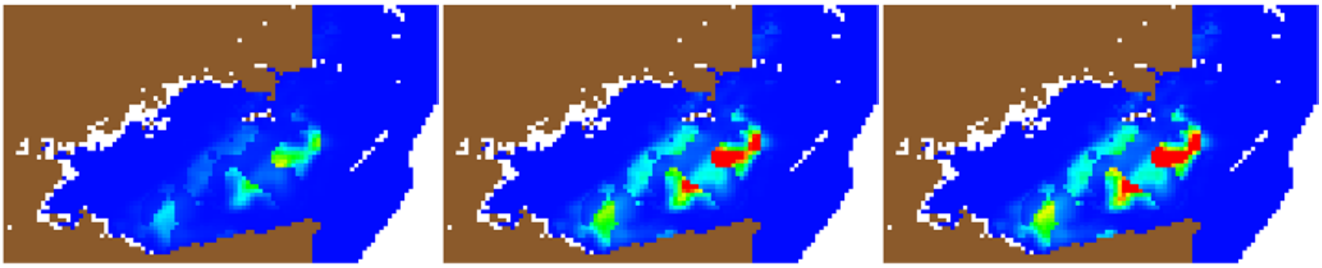
5. "Risk assessment" for benthic faunal groups

For 3 faunal groups for which there were recovery graphics in Collie et al (2000), the example assessment was calculated for 4 sediment substratum categories. In this example, the assessment involved estimating the equilibrium population status relative to unity for each grid cell, assuming the grid effort in section 3 has been applied indefinitely, as 1-*F.d/r* (as above). The patterns of spatial distributions of these faunal groups were unknown and initially not taken into account, i.e. distributions were effectively assumed to be uniform.

The summary results for "Polychaeta" are: overall bay-wide average state = 0.979; average state in trawled cells = 0.955; for "Malacostraca": overall bay-wide average state = 0.946; average state in trawled cells = 0.884; and for "Bivalvia": overall bay-wide average state = 0.939; average state in trawled cells = 0.869. More detailed summary results, by base-2 swept-cover categories and substratum are as follows:

	Summary results for "Polychaeta"				Summary results for "Malacostraca"				Summary results for "Bivalves"			
COVER_IND	Gravel	Mud	mudSand	Sand	Gravel	Mud	mudSand	Sand	Gravel	Mud	mudSand	Sand
0	1	1	1	1	1	1	1	1	1	1	1	1
>0-0.0078125	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
0.015625	0.997	0.999	0.999	1.000	0.993	0.997	0.996	0.999	0.991	0.995	0.996	0.999
0.03125	0.995	0.998	0.998	0.999	0.986	0.995	0.993	0.998	0.982	0.992	0.992	0.998
0.0625	0.990	0.997	0.995	0.999	0.974	0.991	0.986	0.997	0.967	0.986	0.984	0.996
0.125	0.980	0.992	0.990	0.998	0.946	0.976	0.972	0.993	0.932	0.964	0.968	0.993
0.25	0.958		0.982	0.996	0.885		0.948	0.987	0.856		0.942	0.986
0.5	0.917	0.971	0.962	0.991	0.772	0.906	0.890	0.973	0.714	0.861	0.875	0.971
1	0.838	0.958	0.923	0.981	0.555	0.865	0.778	0.944	0.444	0.801	0.749	0.939
2	0.683		0.844	0.967	0.158		0.550	0.903	0.064		0.492	0.894
4	0.428		0.781	0.926	0.000		0.370	0.781	0.000		0.288	0.761
Overall avg state:	0.959	0.994	0.971	0.993	0.903	0.980	0.918	0.981	0.890	0.971	0.907	0.979
Avg in trawled cells:	0.876	0.984	0.956	0.986	0.707	0.948	0.874	0.959	0.668	0.923	0.858	0.956

Bivalves and crustaceans were estimated to be most affected, and in gravel more than in other habitats. Maps of relative impact status for 0.01° cells are presented below. Again, because relative distributions were used, any map of status will strongly reflect the pattern of effort — with a subtle overlay due to impact-recovery differences among sediment types. The same colour ramp is used for all 3 faunal groups ('pristine' status 1=blue, fully impacted status 0=red), so some differences between the 3 groups are apparent.

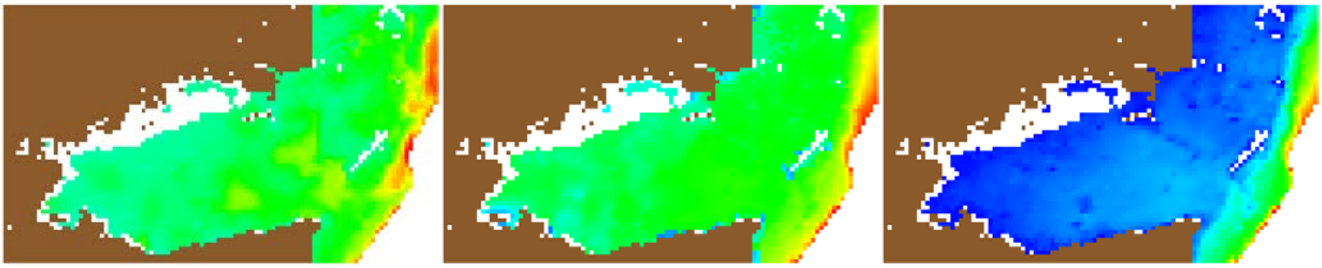


Polychaeta Malacostraca Bivalvia

The Project does not currently have the resources required to progress beyond relative risk assessments; nevertheless, options are currently being pursued that may support an additional post-doc whose role would be to collate large-scale benthos survey data and environmental variables that would allow faunal distributions to be taken into account, similar to the example procedure described in section 6 below.

6. Predicted distributions

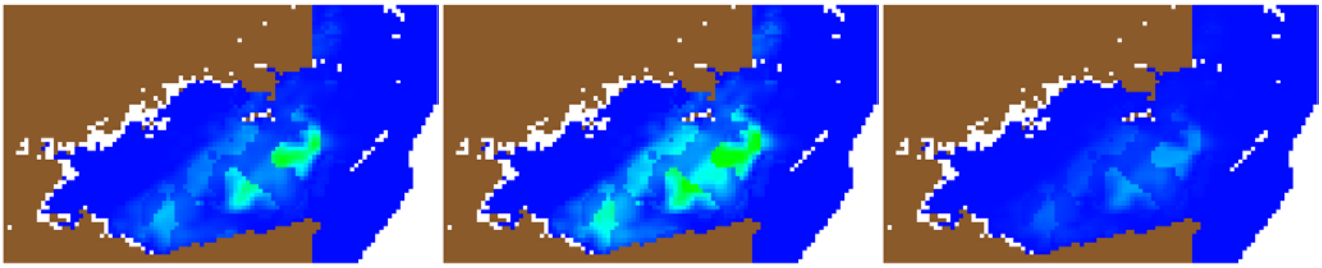
Given real faunal distributions are not uniform, and that some species may be distributed towards and some away from trawled habitats, distributions were predicted for the 3 faunal classes for which impact and recovery rates were estimated. Predictions were made using simple models built from real continental shelf survey datasets. Predictor variables included depth and sediment grain size — in practice, additional useful variables can be acquired and included in models. Each predicted distribution was normalized to provide a profile distribution map for each class (below), for 0.01° grid cells (separate colour ramp is blue = 0 to red = maximum abundance for each class):



Polychaeta Malacostraca Bivalvia

7. "Absolute" risk assessment

An estimate of "absolute" status was made by multiplying relative status by respective predicted distribution profiles, for 0.01° grid cells. The maps of "absolute" status (below) used the same colour ramps as the above distribution profile for the same class (but separate for different classes), to give a visual indication of "absolute" impact status compared with predicted abundance distribution.



Polychaeta Malacostraca Bivalvia

While these “absolute” impact maps appear quite different to the relative impact maps, both in distribution and also in magnitude, the overall regional Class ‘population’ status does not differ greatly from the relative status. For Polychaeta, the “absolute” bay-wide ‘population’ status is 0.976 (compared with overall relative status of 0.979); for Malacostraca, the “absolute” bay-wide status is 0.949 (cf. overall relative status of 0.946); and for Bivalvia, the “absolute” bay-wide status is 0.978 (cf. overall relative status of 0.939). In each case, the estimated “absolute” bay-wide status is slightly better than the relative status, because the predicted distributions are skewed away from trawled areas compared with uniform distributions. In particular, the Bivalves move from being the worst case under relative distributions to the least affected case under predicted distributions because most of their biomass occurs in areas that are not trawled. However, for any species of any faunal groups having distributions skewed towards trawled areas, then population status would be substantively lower.

8. Appendix III

Figures from Collie et al 2000:

Fig. 2: Impact

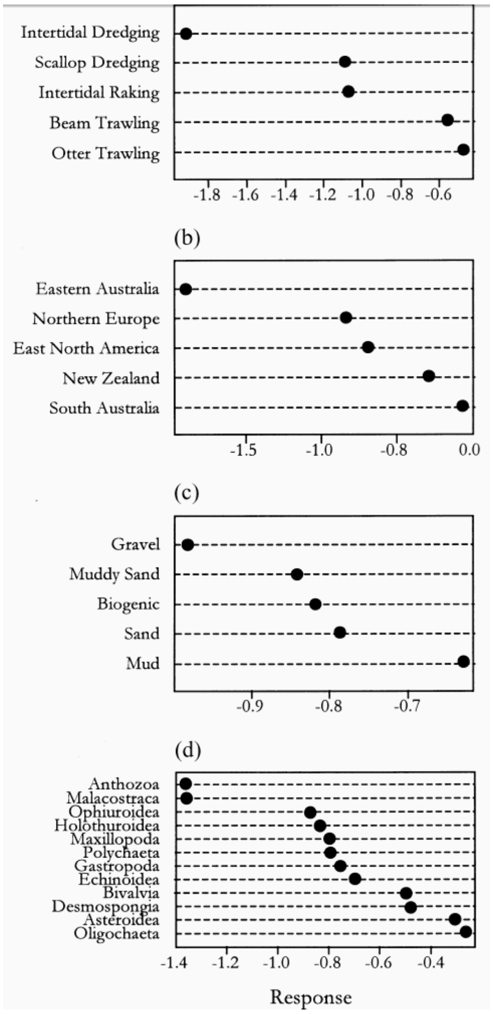
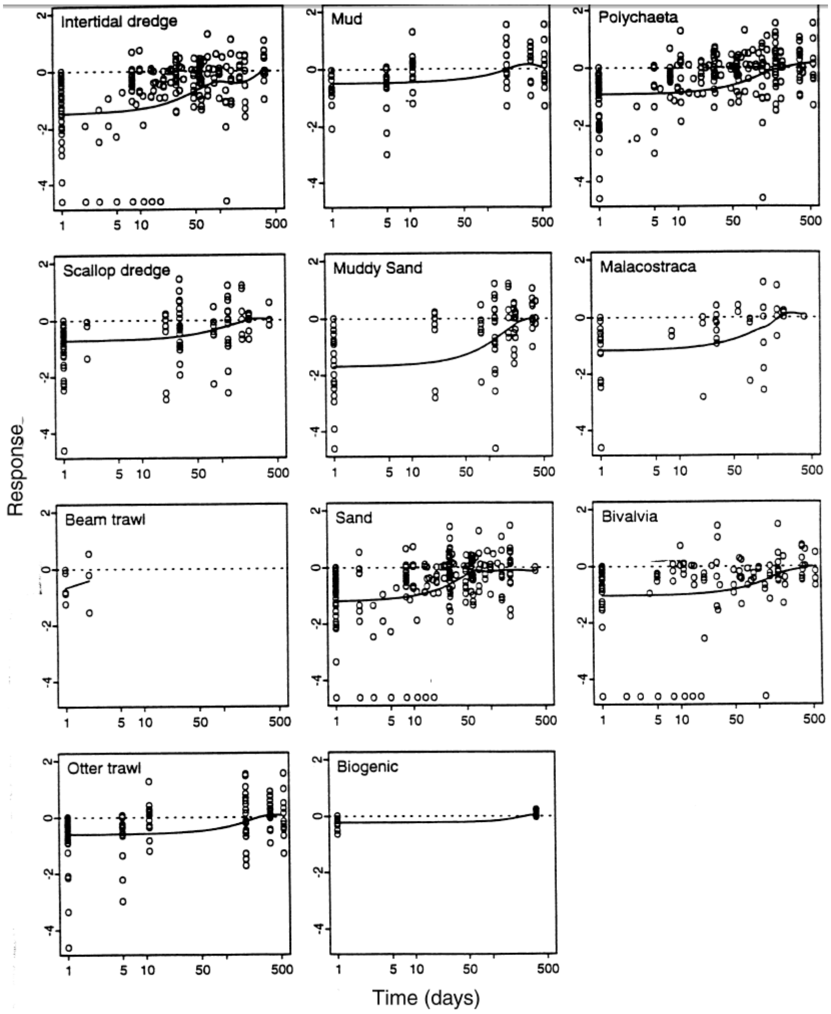


Fig. 5: Recovery



9. References

Collie, J.S., Hall, S.J., Kaiser, M.J., Poiner, I.R., 2000. A quantitative analysis of fishing impacts on shelf-sea benthos. J. Anim. Ecol. 69, 785–798.

Kaiser, M.J., Clarke, K.R., Hinz, H., Austen, M.C.V., Somerfield, P.J., Karakassis, I., 2006. Global analysis of response and recovery of benthic biota to fishing. Mar. Ecol. Prog. Ser. 311, 1–14.