Supporting Information

Text S1. Elaboration of systematic review process

Data were collated from published experimental and comparative studies of the effects of bottom trawling on seabed habitat and biota following a systematic review protocol (1).

‘Bottom trawling’ is defined here to include any commercial towed bottom gear, including otter trawls, beam trawls, scallop dredges and hydraulic dredges used to catch fish and invertebrates living in, on or in close association with seabed habitats. For the systematic review we attempted to find every study in journal papers, book chapters and grey literature reports that reported the effect of bottom trawling on the state of seabed (benthic) taxa (species or higher taxonomic levels) and communities (biomass, abundance, taxon richness and diversity). Each identified study had to pass quality assurance criteria before associated data were included in our analysis (1). This approach eliminated the possibility of bias in selection of the studies. We included studies that reported the effect of bottom fishing activities (exposure) on marine benthic biota (subject) and compared this with effects of no exposure or less exposure to bottom fishing gear (comparator). Studies also had to report a measurable effect (or outcome, non–significant results were included) on at least one identified component of the benthic biota (and to report outcomes from two or more areas of the seabed subject to different intensities of fishing disturbance. Data on the state of benthic biota were extracted from figures, tables or text within publications. We only used studies reporting whole community biomass and/or abundance of macrofaunal invertebrates (infauna and/or epifauna). This includes all species that were effectively sampled, including scavenging species. If essential data were missing, incomplete or contained obvious errors, the lead author was contacted to request these data and these data were included in the analysis if received. 42% of contacted authors responded and provided the requested data, 13% responded but could not supply the requested data, and 44% of authors did not respond. Meta–data were also extracted for each study (including location, depth, gear type, habitat, Table S2 & S3).

Most existing knowledge about fishing impacts has been gained from experimental studies, where abundance of benthic biota is recorded before and after experimental trawling. These studies were used to quantify the direct depletion *d* (or mortality) caused by the pass of a trawl (SI Text S2 for details on the analysis of this data). Comparative (or ‘gradient’ or ‘observational’) studies are studies where the benthic community is compared over a gradient of two or more levels of quantified fishing effort, where trawling effort may have been continuous, seasonal or a single event (SI Text S3 for details on the analysis of these data). The comparative studies allow the estimation of the ratio of *d* to *r*, and estimation of *r* when *d* is known from the experimental studies.

Gear types in the studies were classified as otter trawls (OT), beam trawls (BT), towed dredges (TD) and hydraulic dredges (HD). Otter trawls are widely used in all types of fisheries on a wide range of sediments and target species like gadoids, some flatfishes and prawns. The use of beam trawls is more restricted to sandy and gravelly bottoms and these gears are mostly used to target flatfishes and shrimps. Towed dredges are generally used to target scallops or other bivalve molluscs, and are often fished on gravelly bottoms. Hydraulic dredges are used to target buried bivalves and resuspend sediment to a depth of up to 40 cm. They are often used in intertidal and other shallow areas (2, 3).

Text S2. Estimating depletion from experimental studies and penetration depth

Depletion *d* for macrofauna community biomass and abundance was estimated from the experimental studies identified in the systematic review. Studies used before–after (BA), control–impact (CI), or before–after–control–impact (BACI) designs. 13 of the studies were carried out in areas that were trawled in the last two years but generally at low intensity, 9 were carried out in areas that were last trawled between 10 and 25 years ago, and 10 were carried out in areas that have no fishing history. For the remaining studies this information was not given. Most experiments have therefore been conducted in infrequently trawled and untrawled areas, this is possible because even in the most heavily trawled areas like Europe about one-third of the seabed is not trawled (3). We used the log response ratio (*lnRR*) as the response variable, which was calculated as ln(response fished /response control) for CI studies and ln(response after/response before) for BA studies. The combined variance was calculated as in Borenstein et al. (4). For BACI studies, calculation of the *lnRR* and combined variance was more complicated. Let $y = \log X$ denote the log abundance and consider the four combinations of control/impact and before/after: y_{CB}, y_{CA}, y_{IB}, and y_{IA}. We assumed that effects are multiplicative on the abundance scale, and therefore are additive on the log scale. Let a be the before-after (period) effect, b the treatment effect, and c the interaction term. Then $y_{CB} = \mu$, $y_{CA} = \mu + a$, $y_{IB} = \mu + b$ and $y_{IA} = \mu + a + b + c$.

This means that $c = y_{IA} - y_{IB} - y_{CA} + y_{CB}$. On the abundance scale this implies

$$c = \log\left[\frac{X_{IA}}{X_{IB}} / \frac{X_{CA}}{X_{CB}}\right] \qquad \text{(eq S2.1)}$$

The quantity c is the analogue of lnRR for BACI data. The variance calculation uses the following approximation:

$$\mathrm{Var}[\log X] \simeq \frac{\mathrm{Var}[X]}{[\mathrm{E}X]^2} \qquad \text{(eq S2.2)}$$

This leads to this expression for the variance

$$\mathrm{Var}[c] \simeq \frac{\mathrm{SD}_{IA}^2}{n_{IA}\overline{X}_{IA}^2} + \frac{\mathrm{SD}_{IB}^2}{n_{IB}\overline{X}_{IB}^2} + \frac{\mathrm{SD}_{CA}^2}{n_{CA}\overline{X}_{CA}^2} + \frac{\mathrm{SD}_{CB}^2}{n_{CB}\overline{X}_{CB}^2} \qquad \text{(eq S2.3)}$$

The *lnRR* will be more negative in areas that have been exposed to a higher frequency of fishing disturbance. Therefore, it was corrected using *lnRR* = *lnRR*$_{\text{uncorrected}}$/*Idis* where *Idis* is the number of trawl passes over the fished area.

The number of data points available for estimating *d* was limited: 55 for community biomass and 101 for community abundance (OT: 25, BT: 6, TD: 87, HD: 38). Including the response unit (biomass or abundance) as a factor in the model did not result in a lower AIC, therefore we estimated *d* using both biomass and abundance values in a single model.

Penetration depth of different gear types

Predicted penetration depth (*P*) of each trawl type was estimated from the penetration depth of the individual components of the gear weighted by the width of these components. Penetration depth is defined as the depth to which the sediment was disturbed by the fishing gear, but in practice often measured as the depth to which the sediment was excavated. We conducted a systematic search of the literature starting from Table 6 in Eigaard et al. (5). Each reference in the table was checked and only included when a study directly measured penetration depth. A database of experimental and comparative studies of fishing impacts, produced during a systematic review (1) was also screened for further studies that provided measurements of penetration depth. In addition, references cited within each reference already identified were screened and further studies included as a result. Any study for which penetration depth of a fishing gear (whole), or a gear component, was measured or inferred by one of the following methods was included: underwater video, underwater photographs side-scan sonar, sediment profile images, markers in sediment, observations by SCUBA divers, high resolution acoustic array, underwater laser, inferred from the living position of benthic organisms retained by the fishing gear, or in the case of intertidal fishing methods – by direct observation. Because different methods were used, estimates of penetration depths across studies may not be directly comparable, although they are the best available estimates. Review papers that were not the primary source of penetration depth data were not included, but were used to identify primary sources of data. Studies that reported penetration depths but that were not included in our analysis are given in Table S8.

The sources we identified reported the penetration depth either for the whole gear or for individual gear components (e.g., doors, sweeps, and bridles of an OT). The predicted penetration depth per gear component was therefore estimated by fitting a nested linear model where log(penetration+1) ~ sediment type + Gear|Component. Although we were not directly interested in the effect of sediment type, it was included because within gears the penetration seemed to vary with sediment type and it allowed us to correct for this effect in the final *P* estimates (Gear:Component $F_{9,74}$=6.57, p <0.001, Habitat $F_{3,71}$=2.6, p=0.057). We used the fitted model to predict the penetration depth for each gear component in each sediment type, and estimated the overall *P* for each fishing gear from this in two steps. We first averaged predicted penetration depths over all sediment types for each gear component, and then estimated the mean *P* for each gear by taking the mean weighted by the width of these components.

Text S3. Estimating the effect of trawling in comparative studies

As described in the main text, the responses from different studies were normalised to the common units of *B/K*. *K* was estimated for each of the sampling methods as 10^intercept of the relationship of $\log_{10} B$ versus *F*. In some studies the biota was sampled using two or more methods, each suited to sampling a different component of the community. For example, Hiddink et al. (6) sampled each station across a gradient of trawling frequency with an anchor dredge, box corer and 2m beam trawl. Where two or more sampling methods were used to sample benthic community biomass, *K* was estimated separately for each sampling gear. Studies were treated as replicate measurements by using study as a random effect.

A collective analysis of gradient studies requires fishing pressure to be described on a common scale. We adopted trawling frequency, *F* (y^{-1}), which is equivalent to the swept area ratio ($km^2\ km^{-2}\ y^{-1}$). Trawling frequency expresses how often each cell is trawled i in a year, and is calculated by dividing the area trawled in a year by the area of the study site or other defined area (e.g. grid cell). Trawled area is usually calculated using logbook or vessel monitoring system (VMS) data, from the number of hours spent fishing multiplied by the fishing speed and the width of the fishing gear. Trawling frequency was explicitly reported for about half the comparative studies, and for the other half we calculated trawling frequency from the reported fishing effort (Table S9). Where trawling frequency could not be calculated, the study was excluded from further analyses.

Here we apply eq. 3.1 for estimating the effect of trawling on *B/K* for groups of species and communities. These communities, however, comprise many species with wide variety of *r* and *K* values. Therefore, the response to fishing is the sum of the responses of all those species. Because low–*r* species will be more depleted than high–*r* species, and will potentially be extirpated from the community, the response of the community to *F* is not a straight line as in eq. 3.1. Consequently, the average *r* of the community increases with *F*, and the marginal effect of each additional unit of *F* on community *B/K* decreases with increasing *F*. We simulated a community of species by drawing *r* and *K* values at random, and found that the resulting relationship between total community *B* and *F* is well approximated by a log–linear relationship for normal and exponential distributions of *r* and *K*. We therefore estimated the effect of trawling on communities by fitting a model based on the approximation:

$$\log_{10}(B/K) \sim bF \quad \text{(eq. S3.1)}$$

where *b* is the slope of the relationship. After fitting a linear relationship to $\log_{10} B$ versus *F* for each comparative study, *K* was estimated as the $10\text{\^{}}^{\text{intercept}}$ of this relationship.

Text S4. Estimating *r* from *d* and *b* and quantifying uncertainty

Comparative studies involve sampling the seabed biota at locations within sites subject to different frequencies of trawling disturbance. Collectively, the sampling locations only cover a small proportion of each site, but the mean trawling frequency estimated for the site is assumed to apply to all stations within the site because data on trawl positions are not sufficiently resolved to estimate location-specific trawling frequency. Thus samples linked to the same mean trawling frequency for the site may come from heavily trawled patches, lightly trawled patches, and potentially some untrawled patches, within the site. Consequently, the mean recovery rate estimated for the site (*R*) will not be the same as the intrinsic rate of recovery *r* in equation (1). If the distribution which describes the patchiness of trawling within a site is known then *r* can be estimated following the approach in Ellis et al. (7). Given that $\log_{10}(B/K) \sim bF$ (SI Text S3) and that $B/K = 1 - (d/R)\,F$, it follows that $10^{bF} = 1 - (d/R)\,F$. The equation to estimate *R* from *r* for a single species in Ellis et al. (7, R = r log(1+βd)/[-β log(1-d)]) can therefore be rewritten to estimate *r* for the community as:

$$r = R \Big/ \frac{\log(1+\beta d)}{-\beta\ \log(1-d)} \qquad \text{(eq S4.1)}$$

where

$$R = \frac{-\,d}{\left(10^{b\,F}-1\right)/F} \qquad \text{(eq S4.2)}$$

where β is a parameter defining the spatial distribution of trawling within a site (7). Here we assumed β ≈ 0, representing a random distribution of trawling within a site (in practice $\beta = 10^{-6}$ because the equation is undefined when β = 0). A random distribution within sites is supported by data on the spatial distribution of trawling collected at scales of around 1 km and smaller (8), consistent with the scales at which sites in comparative trawling studies are defined. Assuming a uniform distribution of trawling (β = –1) resulted in *r* estimates that were approximately 10% lower. Equation S4.1 and S4.2 indicate that *r* depends on *F*, which is expected because changes in community composition to favour biota with faster life histories. Because we aim to estimate recovery rates and times for the original unfished community, we used estimates of *r* at *F* = 0 to estimate recovery times. If the distribution of trawling in a cell is random, the site level depletion is the same as local depletion *d* and no correction was therefore applied here.

To propagate the uncertainty in the estimates of *b* and *d* into the estimate of *r* we sampled the distributions of *b* and *d* estimates to derive the distribution of *r*. The value of *b* was taken as negative and –*b* was assumed to have a log-normal distribution, with the standard deviation estimated from the distribution of the random slopes using the *fitdist* function in the *fitdistrplus* package in R (9). The value of *d* was assumed to be positive and bounded between 0 and 1, and to have a logitnormal distribution with standard deviation estimated with the function *twCoefLogitnorm* of the *logitnorm* package in R (10). We sampled 2000 combinations from the distributions of *b* and *d* to estimate the distribution of *r*.

Text S5. Estimating recovery time from *r*

The logistic *r* can be used to estimate recovery time (i.e. *T* from a defined level of depletion below *K* to a defined proportion of *K*). Lambert et al. (11) derived the recovery time *T* to 0.9*K* as:

$$T = \frac{1}{\mathrm{r}}[\ln\left(\frac{0.9K}{B_{t=o}}\right) + \ln\left(\frac{K - B_{t=o}}{0.1K}\right)] \qquad \text{(eq. S5.1)}$$

If we generalise this in terms of any fraction of *K* at which recovery is deemed to have occurred (ϕ) and assume that $B_{t=0}$ is the biomass or abundance of an unimpacted habitat remaining after the pass of a gear that reduces biomass or abundance by a fraction *d*, then the recovery time given these conditions would be:

$$T = \frac{1}{\mathrm{r}}[\ln\left(\frac{\phi K}{K(1-d)}\right) + \ln\left(\frac{K - K(1-d)}{K(1-\phi)}\right)] \qquad \text{(eq. S5.2)}$$

which can be expressed more simply as:

$$T = \frac{1}{\mathrm{r}}\ln\left(\frac{\phi \mathrm{d}}{(1-d)(1-\phi)}\right) \qquad \text{(eq. S5.3)}$$

Table S1. Number of studies of whole community biomass and abundance for macrofauna per gear and habitat. Otter trawls (OT), beam trawls (BT), towed dredges (TD), hydraulic dredges (HD).

a) Experimental studies

	OT	BT	TD	HD
Biogenic	–	–	–	–
Gravel	1	–	1	–
Sand	6	4	16	10
Sandy mud/Muddy sand	–	–	–	2
Mud	5	–	–	1

b) Comparative studies

	OT	BT	TD	HD
Biogenic	–	–	–	–
Gravel	1	–	5	–
Sand	3	4	–	–
Sandy mud/Muddy sand	5	2	–	–
Mud	4	–	–	–

Table S2. Metadata for included experimental studies. A single paper is listed more than once when two or more studies were reported in the same paper.

Source	Region	Habitat	Depth (m)	Gear
(12)	Southern Europe	S	8	TD
(12)	Southern Europe	S	8	TD
(13)	Alaska	S	25	OT
(14)	Southern Europe	S	9	TD
(14)	Southern Europe	S	9	TD
(15)	Southern Europe	S	6	TD
(15)	Southern Europe	S	18	TD
(16)	Australia	S	20	OT
(16)	Australia	M	18	OT
(16)	Australia	S	20	OT
(17)	Northern Europe	S	10	TD
(17)	Northern Europe	S	10	TD
(17)	Northern Europe	S	10	TD
(17)	Northern Europe	S	10	TD
(18)	North America	mS	65	HD
(19)	North America	S	5.5	HD
(20)	Northern Europe	mS	0	HD
(21)	Northern Europe	S	7	HD
(22)	North America	G	70	OT
(23)	Northern Europe	S	21.5	TD
(23)	Northern Europe	S	21.5	OT
(23)	Northern Europe	S	21.5	TD
(24)	Northern Europe	S	26	BT
(24)	Northern Europe	S	34	BT
(25)	Northern Europe	S	0	HD
(26)	Northern Europe	S	30	BT
(26)	Northern Europe	S	30	BT
(27)	North America	S	0.2	HD
(27)	North America	S	0.2	HD
(27)	North America	S	0.2	HD
(28)	Southern Europe	S	24	TD

(29)	Southern Europe	S	23	TD
(29)	Southern Europe	M	11	TD
(30)	South America	S	10	OT
(31)	Canada	S	133	OT
(32)	Southern Europe	M	30	OT
(32)	Southern Europe	M	40	OT
(33)	Australia	S	0	HD
(34)	North America	M	61	OT
(35)	Northern Europe	M	0	HD
(36)	New Zealand	S	24	TD
(37)	New Zealand	S	24	TD
(38)	Northern Europe	M	33.5	OT
(39)	Northern Europe	S	3.5	HD
(40)	South Africa	S	0	HD
(40)	South Africa	S	0	HD

Table S3. Metadata for included comparative studies. sM & mS – sandy mud and muddy sand.

Source	Region	Habitat	Depth (m)	Gear
(41)	South Africa	sM & mS	420	OT
(42)	Eastern North America	Gravel	48	TD
(43)	South Coast Australia	Sand	30	OT
(44)	North Sea	Mud	80	OT
(6)	North Sea	Sand	32.5	BT
(6)	North Sea	Sand	40	BT
(45)	Northwest Europe	sM & mS	31.5	OT
(46)	North west Europe	sM & mS	31.5	OT
(47)	Central North Sea,	sM & mS	57.5	BT
(47)	Central North Sea,	Sand	57.5	BT
(48)	North Sea	sM & mS	50	BT
(49)	Irish Sea	Gravel	43.5	TD
(50)	Mediterranean Sea	Mud	137.145	OT
(51, 52)*	Australia	sM & mS	27.5	OT
(51, 52)*	Australia	Sand	25.5	OT
(53)	Irish Sea	sM & mS	30	OT
(54)	North West Europe	Sand	40	BT
(55)	Eastern North America	Gravel	74	TD
(55)	Eastern North America	Gravel	50	TD
(56)	Australia	Sand	23.5	OT
(57)	North west Europe	Mud	147.5	OT
(57)	North west Europe	Gravel	78.5	OT
(58)	Irish Sea	Gravel	43.5	TD
(59)	North west Europe	Mud	100	OT

* sources combined

Table S4. Penetration depth *P* and depletion *d* of community biomass and abundance for different trawling gears. The 5 and 95% percentiles for *d* estimates are given. Gear types are otter trawls (OT), beam trawls (BT), towed dredges (TD) and hydraulic dredges (HD).

Gear	Penetration depth (cm)			Depletion *d* (fraction)		
	mean	±	sd	5%	Median	95%
OT	2.44	±	1.14	0.02	0.06	0.16
BT	2.72	±	1.24	0.07	0.14	0.25
TD	5.47	±	2.19	0.13	0.20	0.30
HD	16.11	±	5.80	0.35	0.41	0.48

Table S5. AIC estimates of the linear mixed models with different explanatory variables for community biomass and abundance in comparative studies. The model with the lowest AIC for biomass and the two models with the lowest AIC for abundance are given in bold.

Model	Biomass	Abundance
None	**566.9**	89.5
Habitat	573.1	94.3
Gear	572.5	92.4
d	568.9	89.5
Penetration	568.8	89.3
SBT	568.8	89.1
Depth	567.7	91.4
POC	567.7	91.1
PP	568.0	90.9
Gravel	568.4	**81.1**
Sand	568.8	89.2
Mud	568.9	90.2
d/SBT	568.9	89.5
*d**Depth	567.9	90.8
d/POC	568.7	91.1
d/PP	568.8	**86.1**
Penetration/SBT	568.9	90.0
Penetration×Depth	567.8	91.4
Penetration/POC	568.5	91.4
Penetration/PP	568.7	89.0

d = depletion estimate from experimental studies (fraction per trawl pass)

Penetration = penetration depth of fishing gear into the seabed (cm)

SBT = sea bottom temperature (°C)

POC = Particulate organic carbon flux to the seabed (g C_{org} m^{-2} yr^{-1})

PP = Primary production (mg C m^{-2} d^{-1})

Gravel, Sand & Mud = sediment composition in % by weight

Habitat = categorical variable with levels Mud, sM & mS, Sand and Gravel.

Table S6. Parameters used to estimate *r* and percentiles from the distribution of *r* estimates. SD = standard deviation. SAR= swept area ratio.

	Biomass	**Abundance**		
Gear type	Combined	OT	BT	TD
Gravel content (%)	NA	0.84	0.00	44.63
d (fraction)	0.13	0.06	0.14	0.20
SD of *d*	0.08	0.08	0.08	0.08
b (slope)	-0.075	-0.025	-0.015	-0.553
SD of *b*	0.003	0.057	0.057	0.057
% decline with unit increase in SAR	15.90	5.50	3.29	71.99
Recovery time from 0.5*K* to 0.95*K* (years, using median *r*)	3.58	2.81	0.66	16.65
r, 5% percentile	0.42	0.33	2.37	0.11
r, 10% percentile	0.49	0.43	2.75	0.12
r, 25% percentile	0.63	0.66	3.50	0.15
r, 50% percenttile	0.82	1.05	4.49	0.18
r, 75% percentile	1.06	1.66	5.71	0.21
r, 90% percentile	1.34	2.60	7.18	0.25
r, 95% percentile	1.54	3.54	8.21	0.28

Table S7. Studies used to estimate the penetration depth of different gear types. Weighting is the fraction of the width of the gear occupied by a component.

Source	Gear	Component	Habitat	Penetration (cm)	Weighting
(60)	BT	Beam trawl - whole gear	Sand	6	1
(61)	BT	Beam trawl - whole gear	Sand	2.26	1
(61)	BT	Beam trawl - whole gear	Mud	5.29	1
(62)	BT	Beam trawl - whole gear	Sand	1	1
(63)	BT	Beam trawl - tickler chains	Mud	1.4	0.94
(64)	BT	Beam trawl - tickler chains	Sand	0.75	0.94
(65)	BT	Beam trawl - tickler chains	Sand	6	0.94
(63)	BT	Beam trawl - tickler chains	Sand	0.4	0.94
(63)	BT	Beam trawl - tickler chains	Gravel	0.5	0.94
(64)	BT	Beam trawl - tickler chains	Mud	0.9	0.94
(61)	BT	Beam trawl - tickler chains	Sand	1	0.94
(64)	BT	Beam trawl - tickler chains	Sand	0	0.94
(61)	BT	Beam trawl - trawl shoes	Sand	1.9	0.06
(64)	BT	Beam trawl - trawl shoes	Sand	1.5	0.06
(66)	OT	Otter trawl - whole gear	Mud	8.5	1
(67)	OT	Otter trawl - whole gear	Sand	4.5	1
(66)	OT	Otter trawl - whole gear	Sand	0.085	1
(68)	OT	Otter trawl - whole gear	Gravel	4.5	1
(69)	OT	Otter trawl - sweeps	Mud	2.18	0.73
(69)	OT	Otter trawl - ground gear	Mud	1.4	0.25
(70)	OT	Otter trawl - ground gear	Mud	0	0.25
(71)	OT	Otter trawl - trawl doors	Mud	30	0.02
(72)	OT	Otter trawl - trawl doors	Mud	12.5	0.02
(73)	OT	Otter trawl - trawl doors	Mud	5.5	0.02
(73)	OT	Otter trawl - trawl doors	Sand	2.7	0.02
(69)	OT	Otter trawl - trawl doors	Mud	6.43	0.02
(71)	OT	Otter trawl - trawl doors	Sand	20	0.02
(72)	OT	Otter trawl - trawl doors	Sand	2.5	0.02
(74)	OT	Otter trawl - trawl doors	Sand	10	0.02
(75)	OT	Otter trawl - trawl doors	Mud	5	0.02
(75)	OT	Otter trawl - trawl doors	Sand	2.5	0.02
(69)	OT	Otter trawl - trawl doors	Sand	0.26	0.02
(69)	OT	Otter trawl - trawl doors	Sand	2.1	0.02

(69)	OT	Otter trawl - trawl doors	Sand	5.8	0.02
(69)	OT	Otter trawl - trawl doors	Sand	0.2	0.02
(76)	OT	Otter trawl - trawl doors	Gravel	5.5	0.02
(77)	OT	Otter trawl - trawl doors	Sand	15	0.02
(62)	OT	Otter trawl - trawl doors	Mud	14	0.02
(70)	OT	Otter trawl - trawl doors	Mud	4.5	0.02
(75)	OT	Twin Otter trawl - roller clump	Sand	0	0.01
(75)	OT	Twin Otter trawl - roller clump	Mud	0	0.01
(72)	OT	Twin Otter trawl - roller clump	Mud	3.5	0.01
(73)	OT	Twin Otter trawl - roller clump	Mud	12.5	0.01
(76)	OT	Twin Otter trawl - roller clump	Mud	12	0.01
(73)	OT	Twin Otter trawl - roller clump	Sand	3.65	0.01
(66)	OT	Otter trawl - whole gear	Mud	8.5	1
(67)	OT	Otter trawl - whole gear	Sand	4.5	1
(66)	OT	Otter trawl - whole gear	Sand	0.085	1
(68)	OT	Otter trawl - whole gear	Gravel	4.5	1
(69)	OT	Otter trawl - sweeps	Mud	2.18	0.73
(69)	OT	Otter trawl - ground gear	Mud	1.4	0.25
(70)	OT	Otter trawl - ground gear	Mud	0	0.25
(71)	OT	Otter trawl - trawl doors	Mud	30	0.01
(72)	OT	Otter trawl - trawl doors	Mud	12.5	0.01
(73)	OT	Otter trawl - trawl doors	Mud	5.5	0.01
(73)	OT	Otter trawl - trawl doors	Sand	2.7	0.01
(69)	OT	Otter trawl - trawl doors	Mud	6.43	0.01
(71)	OT	Otter trawl - trawl doors	Sand	20	0.01
(72)	OT	Otter trawl - trawl doors	Sand	2.5	0.01
(74)	OT	Otter trawl - trawl doors	Sand	10	0.01
(75)	OT	Otter trawl - trawl doors	Mud	5	0.01
(75)	OT	Otter trawl - trawl doors	Sand	2.5	0.01
(69)	OT	Otter trawl - trawl doors	Sand	0.26	0.01
(69)	OT	Otter trawl - trawl doors	Sand	2.1	0.01
(69)	OT	Otter trawl - trawl doors	Sand	5.8	0.01
(69)	OT	Otter trawl - trawl doors	Sand	0.2	0.01
(76)	OT	Otter trawl - trawl doors	Gravel	5.5	0.01
(77)	OT	Otter trawl - trawl doors	Sand	15	0.01
(62)	OT	Otter trawl - trawl doors	Mud	14	0.01
(70)	OT	Otter trawl - trawl doors	Mud	4.5	0.01
(35)	HD	Hydraulic dredge	Mud	10	1

(18)	HD	Hydraulic dredge	Sand	20	1
(19)	HD	Hydraulic dredge	Sand	5	1
(20)	HD	Hydraulic dredge	Mud	30	1
(21)	HD	Hydraulic dredge	Sand	25	1
(25)	HD	Hydraulic dredge	Mud	10	1
(78)	HD	Hydraulic dredge	Sand	9	1
(79)	HD	Hydraulic dredge	Sand	40	1
(20)	HD	Tractor dredge	Mud	30	1
(80)	HD	Hydraulic dredge	Sand	5	1
(28)	TD	Boat Dredge - whole gear	Sand	6	1
(17)	TD	Boat Dredge - teeth	Sand	3.5	1
(81)	TD	Boat Dredge - teeth	Maerl	10	1
(82)	TD	Boat Dredge - whole gear	Sand	2.5	1
(82)	TD	Boat Dredge - whole gear	Gravel	3.5	1
(82)	TD	Boat Dredge - whole gear	Gravel	5.9	1

Table S8. A list of studies which relate to the physical impacts of towed-bottom fishing gears, but were not included in the penetration depth calculations for the reasons given.

Source	Reason for non-inclusion
(83)	Not the primary source of the reported gear penetration depth
(84)	Penetration depth not reported
(85)	Penetration depth not reported
(86)	Penetration depth not reported
(87)	Review paper, therefore not a primary data source
(88)	Penetration depths obtained from a numerical model, rather than direct measurements
(89)	Penetration depth not reported
(90)	Not the primary source of the reported gear penetration depth
(91)	Not the primary source of the reported gear penetration depth
(92)	Unable to obtain manuscript, however a penetration depth of c. 6.5cm is cited in de Groot (1995) and referenced to this report.
(93)	Not the primary source of the reported gear penetration depth
(94)	The source of the seabed marks measured in the study is ambiguous
(95, 96)	Penetration depth inferred from amount of suspended sediment only, missing non-suspended component of penetration.

Table S9. Trawling frequency calculations for comparative studies where trawling frequency was not reported as the swept area ratio (SAR).

Paper	Region	Habitat	Depth (m)	Gear	Gear	Source of swept area ratio estimate (SA)	Reported effort	Area box	Fishing speed	Gear width (m)	SAR calculation (after converting to the same units)	Min SAR (y^{-1})	Max SAR (y^{-1})
Abbreviation							**E**	**A**	**Sp**	**W**			
Collie et al. 2005	Georges Bank, North America	Gravel	48	Scallop dredge	TD	Calculated	hrs fished y^{-1}	1 nm^2	3 kn	8	E*Sp*W/A	0.0	3.7
Currie et al. 2011	Spencer Gulf , South Eastern Australia	Sand	30	Prawn trawl	OT	Calculated	h km^{-2}		3 kn	29.26	E*Sp*W	0.1	2.9
Frid et al. 1999	Northumberland, NE England, USA	Mud	80	Otter trawls	OT	Calculated	km^2 trawled y^{-1}	ICES††			E/A	0.0	12.9
Jennings et al. 2001a	Silver Pit, North Sea	Sm & Ms	57.5	Beam trawl	BT	Estimated using VMS						0.5	5.4
Jennings et al. 2001b	Hills, North Sea	Sand	57.5	Beam trawl	BT	Estimated using VMS						0.1	2.3
Jennings et al. 2002	Silver Pit, North Sea	Sm & Ms	50	Beam and otter trawls	BT	Estimated using VMS						0.4	5.0
Kaiser et al.	Irish Sea, Isle of	Gravel	43.5	Scallop	TD	Calculate	hrs fished	5x5 nm	2.5 kn	12.0†	E*Sp*W/A	0.1	3.2

2000b	Man			dredge		d	y^{-1}						
Reiss et al. 2009	German Bight, Germany	Sand	40	Beam trawl	BT	Reported						0.1	2.0
Smith et al. 2013a	North East Peak, Georges Bank, N. America	Gravel	74	Scallop dredge	TD	Calculated	hrs fished y^{-1}	50 km^2	3 kn	30	E*Sp*W/A	0.0	0.4
Smith et al. 2013b	CAI, Georges Bank, N. America	Gravel	50	Scallop dredge	TD	Calculated	hrs fished y^{-1}	50 km^2	3 kn	30	E*Sp*W/A	0.0	0.4
Svane et al. 2009	Spencer Gulf, Australia	Sand	23.5	Prawn trawl	OT	Calculated	h trawled per year	645 to 1128 km2	2.5 kn	29.26	E*Sp*W/A	0.2	1.9
Veale et al. 2000	Irish Sea, Isle of Man	Gravel	43.5	Scallop dredge	TD	Calculated	m x h y^{-1}	5x5 nm	2.5 kn	10	E*Sp*W/A	0.0	1.7
Vergnon & Blanchard 2006	Grande Vasiere, Bay of Biscay, France	Mud	100	Nephrops trawl	OT	Calculated	mths fished y^{-1}	ICES rectangle (1 * 0.5 degree)	2 kn	10	E*Sp*W/A	1.6	7.9

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† 16 dredges (10 within 3nmi limit) of 0.75m width.

†† ICES rectangles of size 1° × 0.5°.

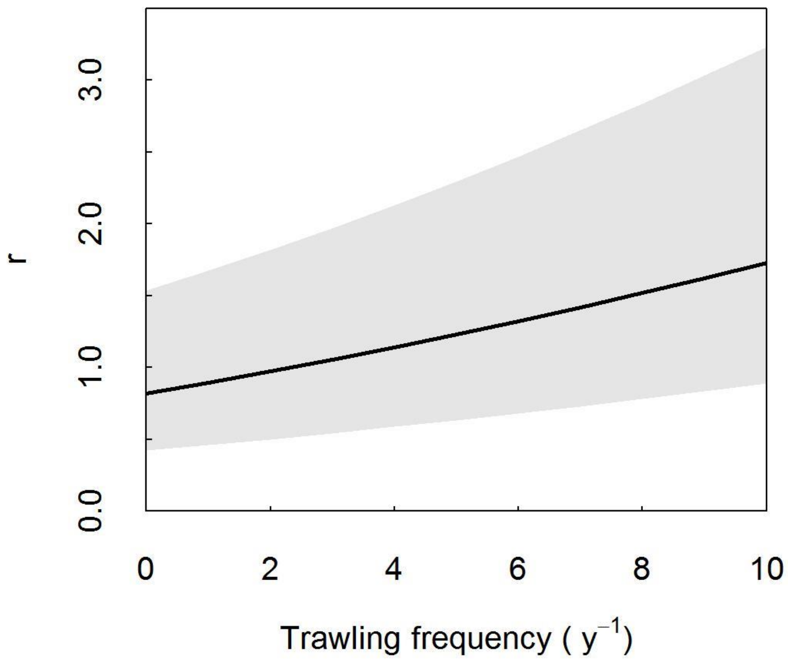

Figure S1. Predicted increase in median *r* (±5-95% quantiles) with trawling frequency for community biomass, as estimated from the relationship between $\log_{10}B/K$ and trawling frequency (equations S4.1 and S4.2). Simulation assumes mean value of *d* over all fishing gears included in the comparative studies (*d* = 0.13).

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