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Spatial and temporal assessment of potential risk to cetaceans from static fishing gears

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ABSTRACT

Ecosystem Based Fisheries Management (EBFM) requires the consideration of potential impacts of a commercial fishery on all components of the ecosystem. Assessment of the impact of commercial fishing on marine mammals generally focuses on species at known risk from bycatch. For cetaceans in particular, inclusion under the Threatened, Endangered and Protected (TEP) species component of Ecological Risk Assessment for the Effects of Fishing (ERAEF) can seem redundant if a species is already known to be at risk or is not thought to interact with the fishery with consequences for its conservation. A spatially and temporally explicit Productivity Susceptibility Analysis (PSA) procedure was developed for inclusion under ERAEF to allow cetacean species to be screened for risk. The technique is demonstrated by assessing the potential risk to harbour porpoise and minke whales from a number of static gear fisheries. The results demonstrate that although a fishery might pose high risk to a species, low or moderate risk areas can exist within the range of the fishery, enabling management measures to focus on areas of greatest risk. Designed to complement and support existing methods of bycatch assessment, this approach is a repeatable and standardised assessment, the outputs of which can be used to systematically document the level of risk posed to different species in a transparent way to aid the inclusion of cetaceans in ERAEF and EBFM both now and in the future.

1. Introduction

A multitude of anthropogenic pressures are focused on coastal waters around the world, impacting cetacean species present in coastal habitats [1]. One of the greatest sources of anthropogenic removal and threat to cetacean populations is from fisheries bycatch. Direct interaction with the fishing industry, both commercial and artisanal, is considered to be the greatest threat to the conservation of cetaceans globally [2]. Fisheries expansion has resulted in an increase in the amount of gear deployed in the world's oceans, increasing the potential for bycatch. Continental shelf waters support over 90% of global fish catches [3] and gear in this habitat poses a great risk to species inhabiting or migrating through it [4].

Bycatch in commercial fisheries can include capture in the main body of mobile gears, with many species such as common dolphin *Delphinus delphis* [5] and white-sided dolphin *Lagenorhynchus acutus* [6] documented in such encounters. Entanglement in passive gears is also a significant problem (e.g. [7,8]) as static gears pose multiple hazards. In addition to the main body of the gear, ropes supporting the gear in the water column pose an entanglement risk for a number of species [9]. Entanglement of cetaceans in static gears is a global problem [10] and gillnets are thought to be the leading cause of bycatch worldwide [7] posing a threat to many marine mammal species (e.g. [11,12]). Harbour porpoise *Phocoena phocoena* is one of the cetacean species most commonly associated with bycatch in gillnets and is vulnerable to the gear throughout its range [7]. A number of programmes are in place which attempt to monitor and mitigate harbour porpoise bycatch (e.g. [13,14]) but harbour porpoise continue to interact with gillnets, particularly in regions beyond those covered by mitigation programmes [14]. The prevalence, and magnitude, of harbour porpoise bycatch can overshadow the threat to other species from gillnets and other static gears. Minke whales *Balaenoptera acutorostrata* and humpback whales *Megaptera novaeangliae* are two examples of species which have also been documented in gillnets, becoming entangled in the gears float lines [12,15,16]. Any lines rising vertically into the water column could be considered to pose a risk to large whale species [9], including longlines and the lines which support pots and traps [7,17].

Management of cetaceans to aid species conservation broadly occurs at two scales. First, legislative backed programmes covering wide areas and a range of species, such as the EU Habitats

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Directive [18], which includes cetaceans under Annex IV(a), and which requires EU member states to maintain certain species at "favourable conservation status" based on the long term viability of the species, the extent of its range and the quality and extent of its habitat. Second, programmes specifically focused on the conservation of marine mammal species, such as the US Marine Mammal Protection Act, which aims to prevent the depletion of populations and restore depleted stocks. Potential Biological Removal (PBR) is included under the Act as a method of assessing anthropogenic impact on populations and is the number of animals considered safely removable from a population [19,20]. Cetacean specific management programmes tend to focus on species at known bycatch risk and, although typically focused on assessing human induced mortality, are generally distinct from the management of the fishery itself.

The conservation of marine mammals is given a broader focus in the context of Ecosystem Based Fishery Management (EBFM), which rather than concentrating solely on sustainability of target commercial species, recognises the impacts of fishing on all aspects of an ecosystem [21]. Ecological Risk Assessment for the Effects of Fishing (ERAEF) is a key tool applied in the context of EBFM. It is a hierarchical procedure used to screen the potential risk posed by fishing activities to species, habitats and communities. As such it enables the impact of fishing on the ecosystem as a whole to be documented in a systematic, transparent and repeatable way, facilitating management and mitigation. In the context of marine mammal conservation the term "risk assessment" typically refers to a model based, fully quantitative approach to assess the impact of anthropogenic factors such as bycatch e.g. PBR. This level of assessment is data intensive and typically applied to species with a known bycatch problem. In data limited scenarios, where many management decisions are taken and conservation plans produced, assumptions and simplifications are often necessary and decisions become subjective and controversial [22].

ERAEF is designed to be applied in data limited scenarios and the outputs can be used to set the context for model based assessment of population viability whilst also allowing action to be taken when the level of data required for such assessments is not available. Originally developed to assess the impact of fisheries in Australia [23], ERAEF are applied to target species (e.g. [24,25]), non-target species (e.g. [26]) and habitats (e.g. [27]). Risk based approaches, in general, are increasingly used to assess impact on non-target species from fishing (e.g. [28,29,30]) and other marine industries (e.g. [31]). A rapid screening protocol was developed to assess the potential risk posed to cetaceans by fisheries [32]. Here a spatially and temporally explicit extension of the preliminary procedure is presented, incorporating data on fishing activity and species distribution to assess and map the potential risk posed by fisheries. The approach is illustrated by an assessment of the relative risk posed by static gears to harbour porpoise and minke whales, in the Irish Exclusive Economic Zone (EEZ). The procedure can be used to highlight areas of highest potential risk to species, allowing research, monitoring and mitigation to be directed. The method illustrated here aims to bridge the gap between fishery management and management of marine mammal populations, allowing species at risk and those unlikely to be impacted by a fishery to be documented in a standardised, transparent procedure which, given the changing state of the oceans, is both flexible and repeatable.

2. Method

The assessment examined the potential risk to harbour porpoise from fisheries deploying gillnets and the potential risk to minke whales from fisheries deploying gillnets, longlines and pots, in the Irish EEZ. The risk assessment was based on Productivity Susceptibility Analysis (PSA) [23,33,34] in which productivity scoring examines the ability of a species to recover from depletion resulting from fishing mortality and susceptibility scoring assesses the likelihood of exposure to fishing mortality, based on the potential for capture and mortality in a particular gear, deployed in a particular fishery [24,35].

2.1. Productivity analysis

Harbour porpoise and minke whale productivity was assessed using four attributes describing reproductive output and longevity [32] (Table 1).

To generate attribute score thresholds a comparison was made of the productivity attribute values of cetacean species occurring in the north east Atlantic. The productivity scores therefore reflect the relative productivity of the species in the assessment (see [32]

Table 1
Productivity and susceptibility attributes, and scoring thresholds and criteria used to generate productivity and susceptibility scores, for cetacean species (from [32]).

	Attribute	High risk (score 3)	Moderate risk (score 2)	Low risk (score 1)
Productivity	Mean age female sexual maturity	$\geq$ 11 years	6–10 years	$\leq$ 5 years
	Oldest reproducing female	$\geq$ 61 years	45–60 years	$\leq$ 44 years
	Calf survival (proportion)	$\leq$ 0.76	0.77–0.89	$\geq$ 0.90
	Inter-calving interval	$>$ 3.5 years	2.6–3.5 years	$\leq$ 2.5 years
Susceptibility	Availability	$>$ 30% Overlap between fishing activity & species distribution	10–30% Overlap between fishing activity and species distribution	$<$ 10% overlap between fishing activity and species distribution
	Encounterability	Overlaps with fishery year round	Overlaps with fishery beyond the assessment period but not year round	Overlap limited to the assessment period
	Selectivity	High potential for capture	Moderate potential for capture	Low potential for capture
	Potential for lethal encounter	Interaction with gear likely to result in death	Interaction with gear likely to result in injury	Interaction with gear unlikely to result in injury or death
	Exposure	$>$ 1 (exposure in cell 10 times mean exposure or more—based on species population and fishing activity)	0 (exposure in cell equalling mean exposure)	< -1 (exposure in cell less than one tenth of mean exposure)

Table 2
Productivity attribute values and sources used to assess the productivity of harbour porpoise and minke whale, and Data Quality Scores (DQS) assigned to each value (mean attribute DQS classified as poor (> 3.5), moderate (2.0–3.5), good (< 2.0) (following [23])).

Species	Attribute	Value	Source	DQS	Mean DQS category
Harbour porpoise	Mean age female sexual maturity (years)	3	[64]	2	2 (Moderate)
	Oldest reproducing female (years)	24	[65]	1	
	Calf survival (proportion)	0.798	[66]	3	
	Inter-calving interval (years)	1.57	[64]	2	
Minke whale	Mean age female sexual maturity	8	[66]	2	2.5 (Moderate)
	Oldest reproducing female	51	[66]	3	
	Calf survival (proportion)	0.806	[66]	3	
	Inter-calving interval	1.0	[66]	2	

for methodology). Attribute values were taken from the literature (Table 2) and for each attribute each species was given a score of 1 to 3, where 3 indicated relative low productivity and anticipated high risk and 1 indicated relative high productivity and anticipated low risk.

Scores were averaged across the four attributes to produce an overall productivity score for each species.

2.2. Susceptibility analysis

The susceptibility of each species to each fishery was assessed in two stages, at two spatial scales and stratified by quarter. This allowed risk scores to be generated for each fishery for the EEZ as a whole, and allowed variation in risk within the EEZ to be examined.

2.2.1. Stage 1: EEZ wide

Overall susceptibility and risk scores were generated for each fishery, for the EEZ as a whole, using four attributes which qualitatively assessed the potential for harbour porpoise and minke whale to encounter fishing activity (Availability a and Encounterability e) and the potential for each species to survive that encounter (Selectivity s and Potential for Lethal Encounter ple) (Table 1). At the level of the EEZ the spatial aspect of the assessment was based on the extent of overlap between the distribution of the species and the distribution of fishing activity. If fishing activity occurred across a large proportion of a species distribution, within the assessment area, risk was considered high as the species had little refuge. The extent of overlap was assessed using Availability scoring for species with distribution maps [23].

The attributes were scored from 1 to 3 where 1 indicated low susceptibility and 3 indicated high susceptibility. The method followed that outlined in [32] with modifications to Availability and Encounterability scoring to allow for spatially and temporally explicit assessment. The overall susceptibility score was a weighted geometric (multiplicative) mean of these scores

$$S = \left(a^2 \times e \times s^2 \times ple\right)^{1/6} \quad (1)$$

with Availability and Selectivity given a weighting of two and the remaining attributes a weighting of one. Weighting Availability and Selectivity ensured that moderate or high scores could not be generated when species distribution and fishing activity did not overlap, or for gears which had low potential to capture a species.

2.2.1.1. Availability. An index of co-occurrence, of species distribution and fishing activity, was used to score Availability [23]. Spatial information on the distribution of harbour porpoise and minke whales, within the EEZ was taken from the SCANS II survey [36]. This ship and aircraft based survey was conducted in July 2005, along the shelf waters of north east Europe. The SCANS II survey generated abundance estimates based on a spatial grid of cells 0.25 by 0.25 degrees, which were translated to corresponding grids of presence and absence for each species.

Vessel monitoring system (VMS) data, for Irish vessels and vessels from other EU countries operating in the EEZ, were used to derive vessel position and indicate the areas of fishing activity for vessels deploying each gear type. VMS were introduced under European Commission legislation (EC 686/97) [37] requiring all vessels of the EU fleet, greater than 15m in length to transmit their position every two hours. VMS data have been in operation on EU vessels greater than 15m in length since January 2005. However, reliable data for the Irish EEZ were not available for 2005. For the purposes of illustrating the technique, data for 2007 were used *in lieu*. VMS records for each gear type were supplied by the Marine Institute and were allocated to a spatial grid of cells, at the spatial resolution of the cetacean distribution data. These grids of activity were translated to corresponding grids of presence and absence of activity, stratified by quarter (1st quarter January–March; 2nd quarter April–June; 3rd quarter July–September; 4th quarter October–December), whereby fishing activity was recorded as being absent from a cell if the total time spent fishing in that cell, in that quarter, was nil.

The presence absence fishing activity grids for each gear type were overlain with the presence absence data for cetaceans, to produce an overall matrix of spatial overlap, or co-occurrence, using ESRI ArcGIS v10. Availability was scored as high (score 3) if fishing activity and cetacean species co-occurred across more than 30% of the species distribution in the EEZ, moderate (score 2) if between 10 and 30% and low (score 1) if less than 10% [23]. Availability was nil where fishing activity did not occur or where the cetacean species was absent. Availability was stratified by quarter and was scored for the EEZ as a whole and these scores used in subsequent assessment of variation in risk across the EEZ. In the absence of data on the seasonal distribution of minke whales and harbour porpoise, species distributions from the July SCANS II survey were used as the distribution of the species in each quarter, for illustrative purposes.

2.2.1.2. Encounterability. Encounterability was scored to reflect habitat and seasonal overlap with fishing activity outside the assessment period. A species whose distribution overlapped with fishing activity year round would be at greater risk than a species which overlapped for a limited period, during a particular season (Table 1). Scoring was based on the Availability scores in each quarter and was low if the species and fishery did not co-occur outside the assessment quarter, moderate if they co-occurred but not in every quarter and high if they co-occurred in each quarter outside the assessment quarter.

2.2.1.3. Selectivity. Selectivity assessed the potential for a gear to capture and retain a species should it encounter it [23]. Selectivity scores were assigned through an expert opinion process [32] with each species given a score of 1 to 3 for each gear type, reflecting the potential for capture (Table 1). Gear classification was deliberately broad, based on Level 5 gear classifications from the EU Data Collection Regulation [38,39]. Gillnets were considered to have high potential for capturing both harbour porpoise and minke whales and were assigned a score of 3. Longlines and pots were considered to have high potential to entangle minke whale and were assigned a score of 3.

2.2.1.4. Potential for lethal encounter. Potential for lethal encounter scored the potential for a species to be killed or injured through an encounter with gear. Harbour porpoise were given a high score (3) for gillnets to reflect the likelihood of fatality resulting from an interaction. As entanglement of large whale species is not always fatal, with many living whales bearing scars suggesting previous entanglement [10,40], minke whales were given a moderate score (2) for each gear to reflect the potential for interaction resulting in injury as a result of entanglement, but not necessarily death. It may be necessary to adjust this score for species for which entanglement is more often fatal.

2.2.2. Stage 2: Variation in susceptibility within the EEZ

To examine and map how susceptibility and potential risk varied within the EEZ, the region was subdivided to a spatial grid of cells, at the spatial resolution of the cetacean and fishing activity distribution data, and relative risk was assessed for each cell. In addition to the four attributes used to score susceptibility for the EEZ as a whole (the values of which remained constant), a fifth attribute, Exposure *ex*, was included, which estimated the potential exposure of the population of a cell to fishing activity in that cell and was based on the abundance of the species and the extent of fishing activity. If fishing activity and species are evenly distributed across the region then risk would be consistent across the region, however, if activity and species were clustered and larger clusters coincided relative risk would be higher in these areas. Exposure was included as a weighted variable and susceptibility calculated using the equation

$$S = \left(a^2 \times e \times ex^2 \times s^2 \times ple\right)^{1/8} \quad (2)$$

2.2.2.1. Exposure. Exposure was based on a method used to assess susceptibility of seabirds to longlines [30] and was based on the abundance of the species and the amount of fishing activity per cell:

$$ex_{cell} = \frac{sp_{cell} \times activity_{cell}}{sp_{EEZ}} \quad (3)$$

Exposure per cell, per quarter, was compared to mean exposure per cell

$$ex_{mean} = \frac{sp_{mean,cell} \times activity_{mean,cell}}{sp_{EEZ}} \quad (4)$$

assuming even distribution of species and fishing activity throughout the year across the region and was converted to a logarithmic scale

$$ex_{score} = \log_{10}\left(\frac{ex_{cell}}{ex_{mean}}\right) \quad (5)$$

Exposure scores were assigned on a scale of 1 to 3 (Table 1). Species abundance per cell was taken from the SCANS II survey data [36] and fishing activity data was based on hours fished per cell and generated from VMS data.

2.3. Risk assessment

The potential risk (R) to each species from each fishery was calculated from the equation

$$R = \sqrt{P^2 + S^2} \quad (6)$$

based on the productivity of the species (P) and its susceptibility to the fishing activity (S). Risk scores ranged from 1 to 4.24 and a species was considered to be at high risk if its score is greater than 3.18, moderate risk if between 2.64 and 3.18 and low risk if less than 2.64 [23]. Species with low productivity and high susceptibility were considered to be at highest risk and those with high productivity and low susceptibility were considered to be at least risk [34]. Potential risk scores were generated, for each fishery, for the EEZ as a whole and on a cell by cell basis, stratified by quarter. The cumulative risk to minke whales from all static gears was estimated based on the proportion of effort by each fishery in each grid cell.

2.4. Data quality, sensitivity and uncertainty

Procedures were incorporated to identify potential sources of uncertainty relating to the quality of the attribute data and the selection of attributes [23]. An attribute data quality index [24] was used to assign data quality scores (DQS) to each attribute to indicate the degree of confidence in the attribute value (Table 3).

Scoring considered the age of the data; the population and species the data were drawn from; and whether the original source was cited and accessible for verification. Mean attribute DQS were calculated for each species and were classified as poor (>3.5), moderate (2.0–3.5) or good (<2.0) [23] (Table 2). DQS are used to identify knowledge gaps in the assessment, with poor DQS indicating areas where more research is needed. Where several estimates were available for a species attribute value, preference was given to the estimate with better DQS. Where DQS were equal the precautionary approach was applied and the most conservative estimate, generating the highest risk score, was used. Published data, specific to the assessment region were used, where possible. Sensitivity analysis was conducted to test the appropriateness of the attributes used to generate the risk scores. PSA

Table 3
Data quality score definitions for cetacean productivity attributes (following [24]).

Data quality score	Category	Description	Example
1	Best	Substantial data for stock and area of interest	Published literature using multiple methods
2	Adequate	Data with limited coverage and corroboration, or not as reliable as Tier 1 data	Limited temporal/spatial data/old information/outside region
3	Limited	Estimates with high variation/limited confidence and/or based on similar taxa or life history strategy	Similar genus/family/based on captive animals or estimated from other parameters
4	Very limited	Expert opinion or based on general literature review from wide range of species	General data, not referenced
5	No data	No information to base score on	

Table 4
Estimated potential risk to harbour porpoise and minke whale, across the EEZ as a whole, from fisheries deploying static gears, based on productivity of the species and its susceptibility to the gear, and uncertainty in the PSA scores generated by the full attribute set, assessed by dropping each attribute in turn and calculating the standard deviation (SD) of the resulting PSA scores and the upper and lower 95% confidence intervals (CI).

		Quarter	Mean age sexual maturity	Oldest reproducing female	Calf survival	Inter-calving interval	Productivity score	Availability (% co-occurrence)	Encounterability	Selectivity	PLE	Susceptibility score	PSA score	PSA SD	Upper 95%	Lower 95%
Harbour porpoise	Gillnet	First	1	1	2	1	1.25	3 (37)	3	3	3	3.00	3.25 High	0.04	3.27 High	3.24 High
		Second	1	1	2	1	1.25	3 (52)	3	3	3	3.00	3.25 High	0.04	3.27 High	3.24 High
		Third	1	1	2	1	1.25	3 (52)	3	3	3	3.00	3.25 High	0.04	3.27 High	3.24 High
		Fourth	1	1	2	1	1.25	3 (32)	3	3	3	3.00	3.25 High	0.04	3.27 High	3.24 High
Minke whale	Gillnet	First	2	2	2	1	1.75	3 (37)	3	3	2	2.80	3.31 High	0.09	3.34 High	3.26 High
		Second	2	2	2	1	1.75	3 (52)	3	3	2	2.80	3.31 High	0.09	3.34 High	3.26 High
		Third	2	2	2	1	1.75	3 (52)	3	3	2	2.80	3.31 High	0.09	3.34 High	3.26 High
		Fourth	2	2	2	1	1.75	3 (32)	3	3	2	2.80	3.31 High	0.09	3.34 High	3.26 High
	Longlines	First	2	2	2	1	1.75	3 (34)	3	3	2	2.80	3.31 High	0.09	3.34 High	3.26 High
		Second	2	2	2	1	1.75	3 (38)	3	3	2	2.80	3.31 High	0.09	3.34 High	3.26 High
		Third	2	2	2	1	1.75	2 (25)	3	3	2	2.45	3.01 Mod	0.13	3.07 Mod	2.96 Mod
		Fourth	2	2	2	1	1.75	3 (30)	3	3	2	2.80	3.31 High	0.09	3.34 High	3.26 High
	Pots	First	2	2	2	1	1.75	2 (16)	3	3	2	2.45	3.01 Mod	0.13	3.07 Mod	2.96 Mod
		Second	2	2	2	1	1.75	2 (16)	3	3	2	2.45	3.01 Mod	0.13	3.07 Mod	2.96 Mod
		Third	2	2	2	1	1.75	2 (17)	3	3	2	2.45	3.01 Mod	0.13	3.07 Mod	2.96 Mod
		Fourth	2	2	2	1	1.75	2 (17)	3	3	2	2.45	3.01 Mod	0.13	3.07 Mod	2.96 Mod

scores were generated for each species by dropping each attribute in turn until all attribute combinations had been used. The standard deviation of the resulting PSA scores was a measure of the uncertainty of the scores generated for each species. The mean PSA score and upper and lower confidence intervals were calculated, compared with the risk score generated by the full attribute set and discrepancies noted (Table 4).

3. Results

3.1. Species attributes and distribution

Harbour porpoise had the lowest "mean age at sexual maturity" and lowest "oldest reproducing female" of the species occurring in the north east Atlantic, and their high relative productivity generated low risk scores for each attribute. The species relatively short inter-calving interval also resulted in a low risk score, suggesting relative high productivity. Calf survival was moderate, indicating moderate risk. Overall harbour porpoise scored 1.25 in relative productivity (Table 4) indicating a low to moderate biological risk from bycatch, relative to other cetacean species. Minke whales generated moderate productivity scores for all productivity attributes with the exception of inter-calving interval, which was the lowest of the cetacean species occurring in the north east Atlantic. Overall minke whale scored 1.75 in relative productivity, indicating it was less productive than harbour porpoise and generating a low to moderate risk score. Harbour porpoise were present in every cell of the EEZ. Minke whales were also present throughout the EEZ with the exception of three cells where they were absent [36].

3.2. Data quality, sensitivity and uncertainty

Mean data quality scores were moderate for harbour porpoise and minke whale and no attribute data were missing (Table 2). Sensitivity analysis was conducted for each EEZ wide risk assessment. The upper and lower risk estimates produced by the sensitivity analysis were consistent with those produced by the full attribute set, indicating the attributes selected were appropriate for the assessment (Table 4).

3.3. Potential risk from gillnets

Of the fisheries examined, gillnets were deployed over the largest area in the EEZ. The extent of co-occurrence was the same for harbour porpoise and minke whale generating the same scores for Availability. In each quarter co-occurrence exceeded 30% of species distribution generating high Availability scores (Table 4) and peaked in the second and third quarters when each was exposed to gillnet activity across more than half (52%) their distributions. The consistency of co-occurrence throughout the year generated high Encounterability scores ensuring that, at the scale of the EEZ, harbour porpoise and minke whales were assessed as being at high risk from gillnets (Table 4).

On a cell by cell basis the distribution and scale of potential risk from gillnets differed between the species (Figs. 1 and 2). Where harbour porpoise and gillnet activity overlapped the majority of cells were low risk, with the exception of the fourth quarter when moderate cells dominated (Fig. 1). High risk cells peaked at 18% in the second quarter, falling to a low of 3% in the fourth, and were broadly confined to waters off the south coast of Ireland. Moderate risk cells occurred throughout the harbour porpoise distribution, but were concentrated in waters off the south and west coasts.

Where minke whale and gillnet activity overlapped the majority of cells scored moderate risk (Fig. 2), peaking in the third quarter, when 48% of cells with minke whales were classified as such. High risk cells occurred off the west and south coasts, peaking at just 8% in the second quarter. Less than 1% of cells where minke whales were present scored low risk, occurring in isolated patches off the east coast in the third quarter.

3.4. Potential risk from longlines

Longlines were deployed in the EEZ throughout the year and co-occurrence with minke whales ranged from a high of 38% in the second quarter to a low of 25% in the third quarter (Table 4). The fishery was classified as posing potentially high risk in the first, second and fourth quarters and moderate risk in the third quarter (Table 4).

Moderate risk activity dominated where minke whale distribution overlapped with longline activity in the EEZ (Fig. 3). In the first, second and third quarters, 6%, 8% and 5% of cells were classified as high risk. In each quarter high risk cells were largely confined to the northwest and southwest boundaries of the EEZ. Low risk longline activity was confined to the third quarter when 11% of cells were classified as such.

3.5. Potential risk from pots

Pots were assessed as posing moderate risk to minke whales across the EEZ as a whole, co-occurring with between 16% and 17% of minke whale distribution in each quarter (Table 4). Within the EEZ, where minke whale distribution overlapped with pot activity, the majority of cells were classified as moderate risk (Fig. 4). Between 12 and 15% of cells with minke whales present were classified as moderate risk throughout the year and were largely confined to waters off the north coast. Low risk cells were also present in each quarter, with between 2 and 4% of cells classified as such.

3.6. Cumulative risk to minke whales

Across the EEZ the cumulative exposure of minke whales to static gears was substantial, with static gear activity occurring across more than half of minke whale distribution (Fig. 5). Static gear activity overlapped with more than 50% of minke whale distribution, peaking in the second and third quarters when just 29% of minke whale distribution was free of static gear activity. On a cell by cell basis 61% of cells in which minke whales were present were classified as moderate risk cells. 15% of cells were classified as high risk, peaking in the second quarter. Low risk cells accounted for 11% of the cells in which minke whales were present.

4. Discussion

4.1. Risk assessment

ERAEF is a flexible, hierarchical procedure which users can modify to reflect the objectives of their assessment and the level of data available to them. The results of this assessment, which must be interpreted within the limits of the data used, indicated regional and seasonal variation in potential risk, reflecting variation in fishing activity, vulnerability to different gears and potential for surviving interactions with gear. The risk assessment output indicated that, during the period covered by the study, risk to minke whales from static gears varied across the EEZ. Minke whales are the most frequently reported Mysticete in Irish stranding records [41] with many strandings in the UK showing evidence of entanglement [10]. Entanglement is a conservation

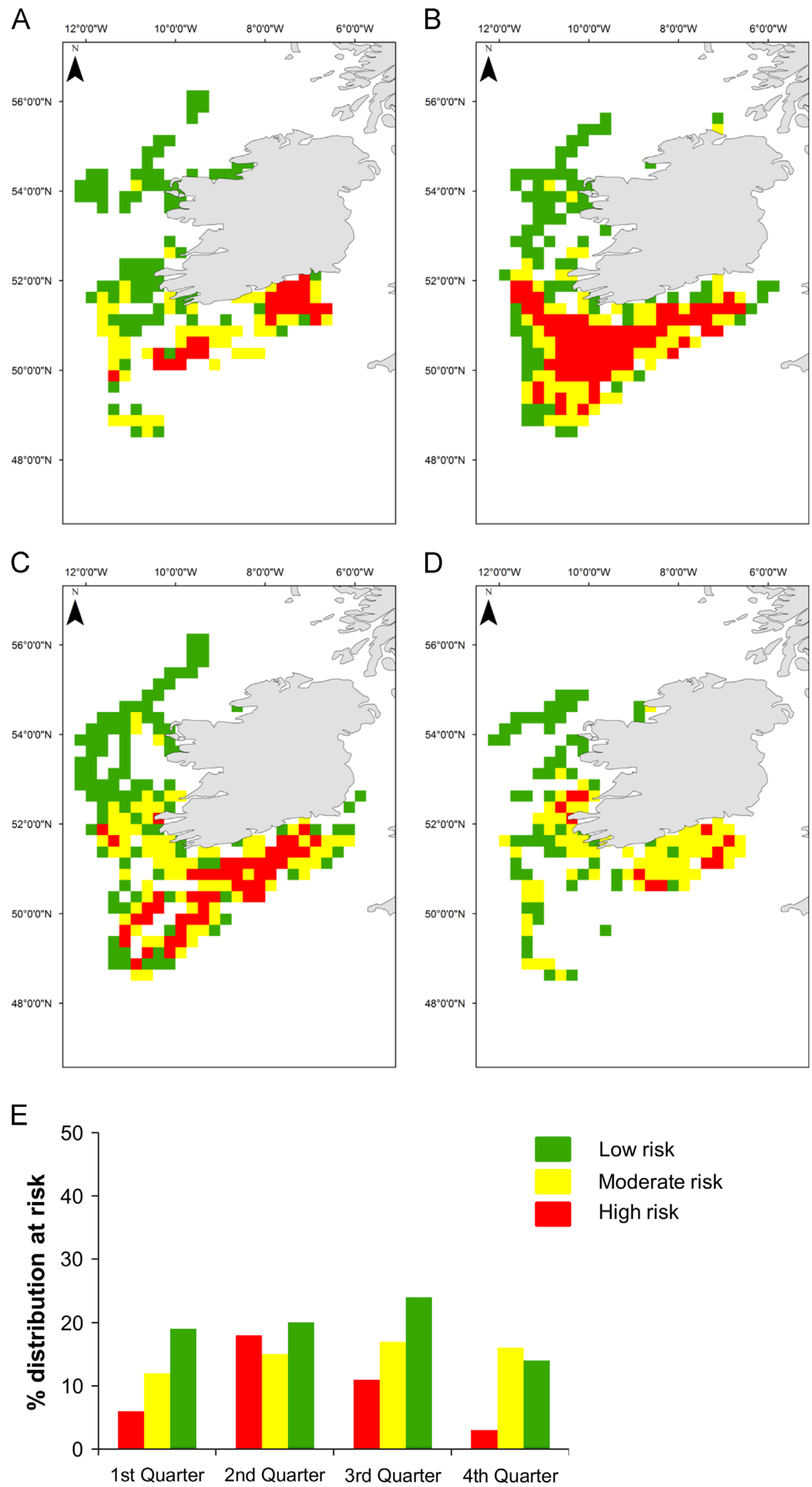

Fig. 1. Relative risk to harbour porpoise from gillnets deployed in the Irish EEZ incorporating potential exposure to gear in (A) 1st quarter, (B) 2nd quarter, (C) 3rd quarter, (D) 4th quarter and (E) the area of species distribution subject to each risk category.

issue for several Mysticete species and regions, most notably for the critically endangered North Atlantic Right whale *Eubalaena glacialis* [42,43]. Large whale entanglement is also considered an animal welfare issue [44] as entanglement can be cryptic, with whales breaking free and swimming away carrying gear, eventually succumbing to starvation or infection [44]. Mortality

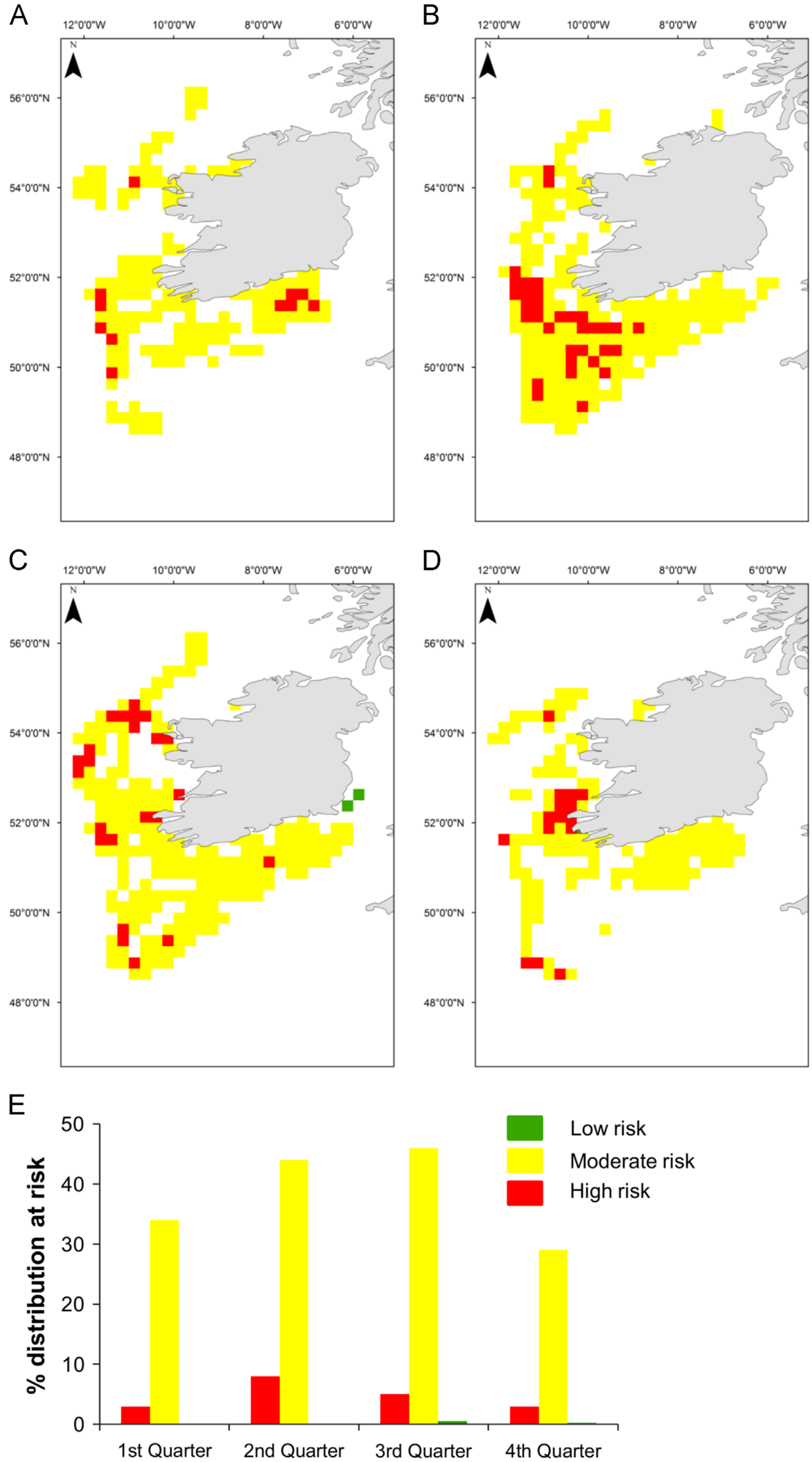

Fig. 2. Relative risk to minke whale from gillnets deployed in the Irish EEZ incorporating potential exposure to gear in (A) 1st quarter, (B) 2nd quarter, (C) 3rd quarter, (D) 4th quarter and (E) the area of species distribution subject to each risk category.

resulting from entanglement is likely underestimated [45]. Whilst there is no evidence to suggest that entanglement in fishing gear currently poses a threat to the conservation of minke whales in Irish waters, the results suggest there may be elevated risk of entanglement at certain points within this area of the species range.

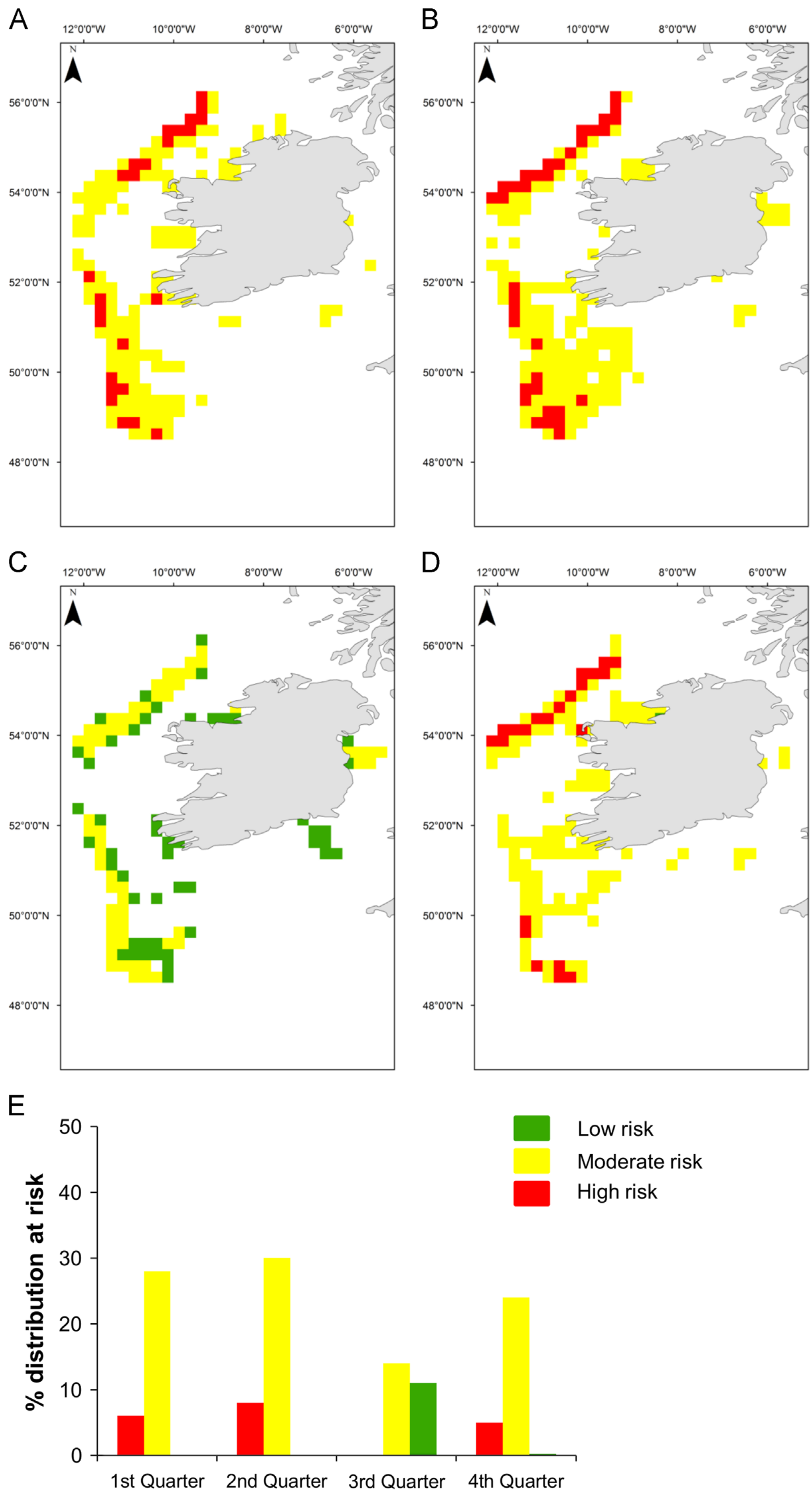

Fig. 3. Relative risk to minke whale from longlines deployed in the Irish EEZ incorporating potential exposure to gear in (A) 1st quarter, (B) 2nd quarter, (C) 3rd quarter, (D) 4th quarter and (E) the area of species distribution subject to each risk category.

Gillnets are used around the world and harbour porpoise are extremely vulnerable to them with mortality exceeding sustainable levels in several areas [46]. The assessment identified areas of potential high risk off the south coast of Ireland. This corresponds to the Celtic Sea region where bycatch of harbour porpoise is a known concern [47] and where Acoustic Deterrent

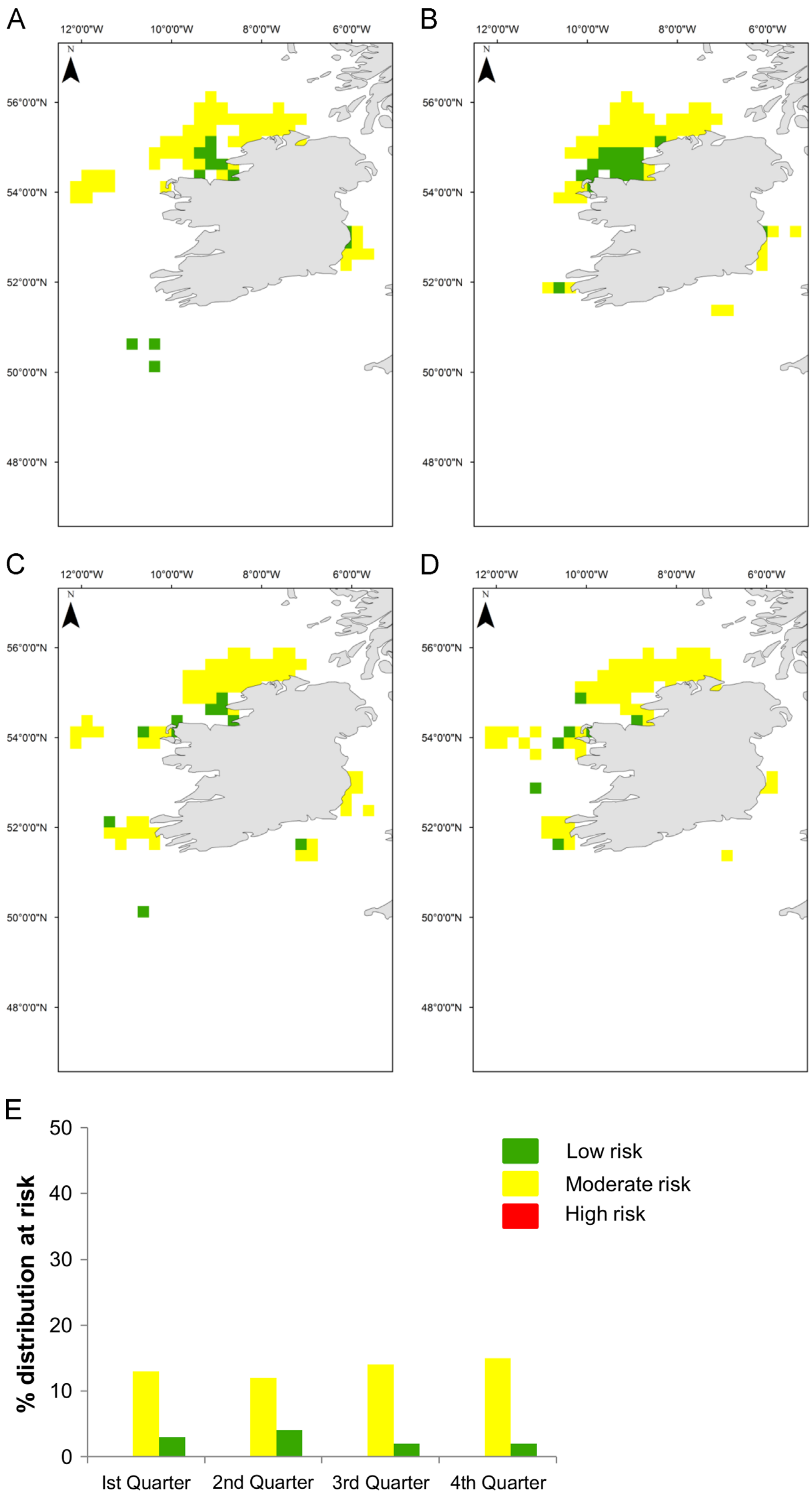

Fig. 4. Relative risk to minke whale from pots deployed in the Irish EEZ incorporating potential exposure to gear in (A) 1st quarter, (B) 2nd quarter, (C) 3rd quarter, (D) 4th quarter and (E) the area of species distribution subject to each risk category.

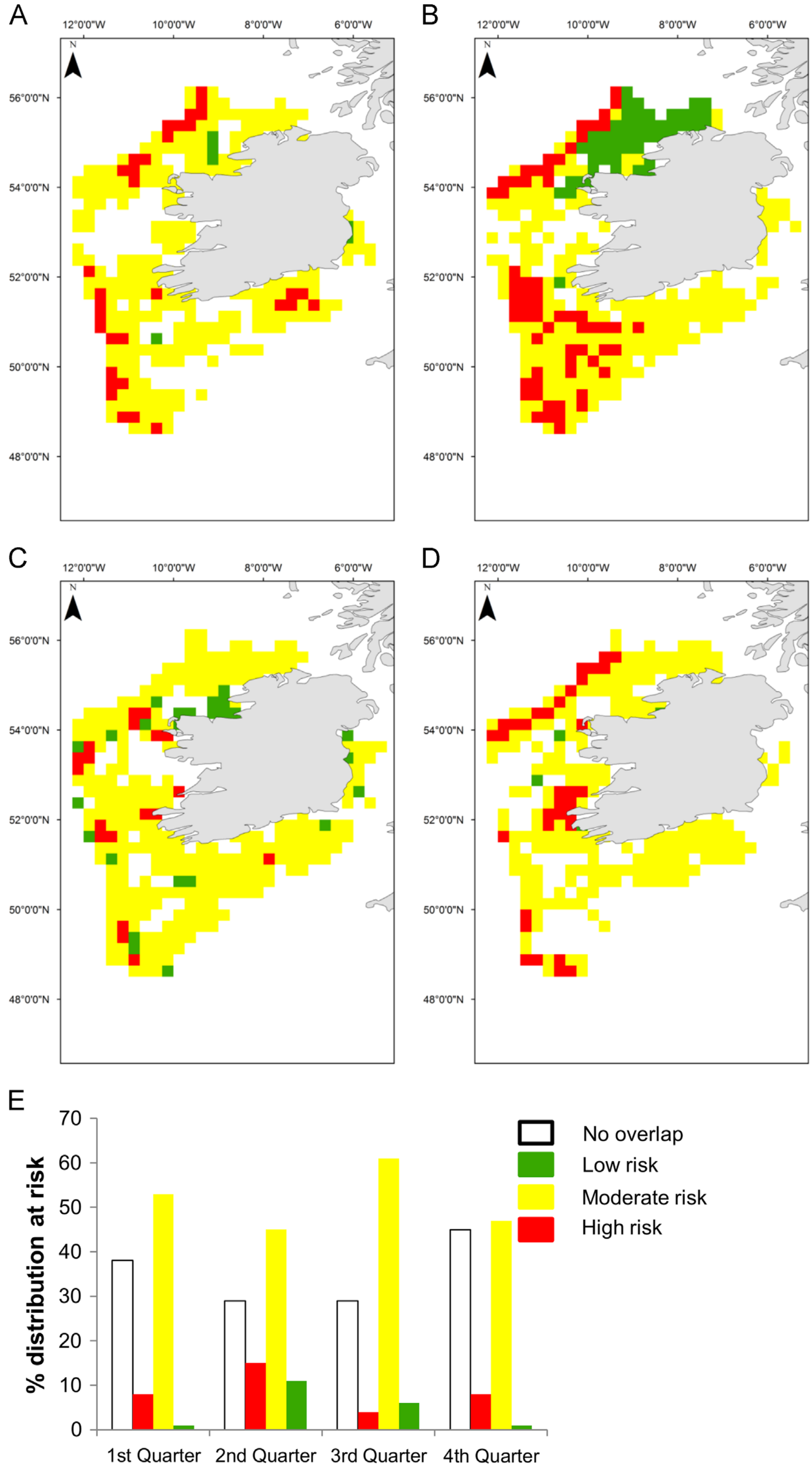

Fig. 5. Cumulative risk to minke whales from all static gears deployed in the EEZ in (A) 1st quarter (B) 2nd quarter, (C) 3rd quarter and (4) 4th quarter.

Devices (ADDs) are mandatory in certain fisheries [48,49], demonstrating the procedure is effective in highlighting potential risk areas.

In order to illustrate the assessment procedure in a clear and concise way fishery classification was deliberately broad, and mitigation measures to reduce bycatch were not included. Bycatch reduction measures can be considered during the procedure to refine the results of the assessment, or as a management response. Although beyond the scope of this paper given the temporal mismatch of the fishing activity and cetacean species distribution data, spatial risk assessments can contribute to the optimal deployment of for example, ADDs and time area closures by allowing the risk to multiple species in multiple areas to be considered concurrently. In scoring selectivity the assessment did not consider factors such as mesh size, acoustic deterrents, or whether in the instance of harbour porpoise and gillnets the gear was set within the diving range of the species. The assessment is designed as a rapid first step to assess and map risk. This information could be incorporated into the assessment if available, but the procedure is robust and flexible enough to allow for assessment in cases where it is not.

4.2. Expanding the assessment

This assessment of exposure focused on fishing activity, based on hours fished and conducted on the assumption that the more activity in an area the greater the potential for encountering gear and the greater the risk. In certain scenarios it may be appropriate to quantify exposure based on fishing effort, if such data is available. Effort by static gears depends on a number of factors including soak time and gear dimensions, such as net length or the number of pots or hooks deployed (e.g. [30]), and was not available for the EEZ. VMS data are used to estimate effort for mobile gears, based on hours fished [50] but fishing effort using passive gears is difficult to quantify using VMS data alone [51]. The systematic documentation of effort by static gears will be required if the risk posed by these gears is to be fully appreciated.

The method presented here is intended as a starting point and should be adapted to suit the specific objectives for, and characteristics of, the species and fisheries being assessed. Incorporating accurate estimates of fishing effort in calculating potential exposure to a fishery is complicated by a lack of understanding of the mechanism by which cetacean bycatch occurs. There is evidence to suggest that the mechanism varies between species and gear and therefore the most appropriate measure of fishing effort will also vary. For instance, common dolphins are vulnerable to capture in trawls during hauling [5], failing to abandon gear as the net collapses [52]. There is no correlation between dolphin bycatch and tow duration [5] therefore the number of hours fished has little bearing on the potential for bycatch occurring. Rather, exposure to gear is better quantified by the number of fishing events taking place. For large whale species vulnerable to lines in the water column, potential exposure would be driven by the amount of gear deployed, its soak time and the structure of the gear in the water column, and these measures of fishing effort would be most appropriate. Documenting effort by static gears may also shed light on the mechanism by which bycatch occurs if conducted alongside the recording of bycatch events through on-board observer programmes.

A complete assessment of a fishery should include effort by an entire fleet. This assessment used VMS data to identify fishing areas and estimate levels of activity and is therefore biased towards larger vessel activity [53]. Incorporating activity from smaller boats is vital as these vessels typically operate in coastal waters predominantly deploying static gears [54] and therefore potentially pose a substantial risk to cetacean species inhabiting shelf waters. Currently, the effort deployed by such vessels remains largely unquantified [54] in both developed and developing countries [55]. In the absence of VMS data for boats less than 15 m in length, other methods are required to monitor the position and extent of effort by static gears. One option may be to conduct either opportunistic or structured sighting surveys of gear marker buoys or interviews of boat crew or skippers [10] to determine the timing and location of effort, and potentially the amount of gear in the water. A similar approach could also be used to gather information on static gear effort by larger boats at a resolution necessary for the assessment.

4.3. Cetacean abundance and distribution

Ecosystem based fisheries management is most likely to be achieved through developing spatially explicit models of the distribution of fishing activity, target and non-target species and habitats [53] but such assessments will always be limited by the quality, age and extent of the data used to map fishing activity and species distribution. Data on distribution of minke whales and harbour porpoise used in the assessment came from the SCANS II survey [36]. This survey was conducted in 2005, and was restricted to one season, but remains the most comprehensive and recent information for the study area. The risk scores shown here are an illustration of the approach and may be markedly different if up to date species distribution information were used alongside up to date estimates of the location of fishing activity, as evidence from the SCANS II survey suggests that the distribution of harbour porpoise and, to a lesser extent, minke whales is changing [36]. Likewise, minke whales and harbour porpoise may vary in seasonal distribution in the region [56,57] and incorporating seasonal information on cetacean distribution would provide a robust indication of the locations of high risk areas. In European waters there is an urgent need for up to date, seasonal estimates of the abundance and distribution of species and habitats [53] and the extent of bycatch, not only to fulfill obligations under the Habitats Directive, Marine Strategy Framework Directive and Common Fisheries Policy to manage the ecosystem impacts of fisheries, but to ensure potential problems are identified promptly. Surveys using platforms of opportunity (POPS) can help fill knowledge gaps on seasonal distributions [58,59] and contribute to the risk assessment process.

4.4. Bycatch mitigation and spatially explicit assessment

Spatially explicit assessments, using a variety of techniques and procedures are being implemented for specific species in discrete areas. The dugong *Dugong dugon*, for example, occurs in an ecosystem scale network of Marine Protected Areas which make up the Great Barrier Reef World Heritage Area [60]. The species is impacted by a number of human pressures and bycatch is managed through area closure. Spatial risk assessments were used as decision support tools to identify sites for area closure [60,61]. The Take Reduction Plan implemented to reduce bycatch of harbour porpoise in the Gulf of Maine in 1999 was based on spatial assessment of bycatch risk and the implementation of time area closures [46,62]. The location of closures was supported by detailed information on harbour porpoise abundance and the location of bycatch determined through on board observer programmes. Our approach follows a similar principle but allows the assessment of relative risk from different fisheries, and to different species. The technique can be directly applied to a range of cetacean species and gear types (see [32] for details), either in isolation or as a group, depending on the objectives of the assessment, and could be easily adapted to assess other marine mammals. It can be applied at a range of spatial scales, from species wide assessments to smaller scale localised studies, and could have a role in establishing the boundaries of, and managing the activities within, areas designated for the protection of cetacean species, such as the establishment of Marine Protected Areas.

5. Conclusion

Anthropogenic disturbance of coastal ecosystems is expanding and intensifying [63], increasing the pressure on the organisms these habitats support. The growing call for a more holistic approach to ecosystem management is particularly pertinent for coastal habitats, where the cumulative impacts of fishing, exploration, extraction, tourism and recreation can be substantial. Marine fisheries and marine mammals have traditionally been managed under separate legislative mandates [2] and without a more holistic approach the issue of marine mammal bycatch will remain difficult to monitor and mitigate. Management of marine mammal populations typically seeks to maintain population sizes or enable previously depleted populations to grow, within the context of clearly defined management goals [22]. The Revised Management Procedure (RMP) applied by the International Whaling Commission (IWC) to determine sustainable harvest levels for specific populations of large cetaceans, aims to estimate the number of animals that can be removed from a population whilst maintaining the viability of that population [22,46] and like the PBR, is a relatively data intensive, quantitative approach, requiring estimates of abundance, life history parameters and bycatch rate [20] and is appropriate for scenarios where mortality is directly observable [22]. This approach is not designed to replace these assessments but to support their implementation by identifying areas where the potential for bycatch is higher, or species for which the potential risk is greater, enabling the prioritisation of resources for further research and monitoring. It is a broader approach examining the potential impact on all species, not just those known to be, or thought to be, at high risk. Stakeholder participation is vital for the success of any management or mitigation regime [46] and can be readily incorporated into the assessment. Participation in such assessments can help encourage acceptance and compliance in management outputs that may arise [23] and including a spatial and temporal element not only refines the assessment but provides a clear method of communicating the results [61]. Fully quantitative model based assessments, such as PBR or RMP, are supported at subsequent levels of the hierarchical ERAEF procedure for species identified as being at moderate or high risk, and for which appropriate data are available, but the approach allows management measures to be put in place in scenarios where data are not available [23]. The approach can be applied to screen the impacts of range of fisheries, on a range of species [32] allowing impacts to be documented in a clear and transparent way for use both now and in the future.

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