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Disentangling the causes of protected-species bycatch in gillnet fisheries

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Abstract

Gillnet fisheries are widely thought to pose a conservation threat to many populations of marine mammals, seabirds and turtles. Gillnet fisheries also support a significant proportion of small-scale fishing communities worldwide. Despite a large number of studies on protected species bycatch in recent decades, relatively few have examined the underlying causes of bycatch, and fewer still have looked at the issue from a multi-taxon perspective. We used three bibliographic databases and one search engine to identify studies by year of publication and taxon. The majority of studies on the mechanisms of gillnet bycatch are not

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accessible through mainstream published literature sources. Many are reported in technical papers, government reports and University theses. We reviewed over 600 published and unpublished studies of bycatch where causal or correlative factors were considered, and identified therein 28 environmental, operational, technical and behavioral factors that might plausibly be associated with higher or lower bycatch rates of the three taxa. Of the factors considered, 11 were found to have been associated with potential bycatch reduction in two out of the three taxa, while three factors (water depth, mesh size and net height) were associated with trends in bycatch rate for all three taxa. These findings provide a basis to guide further experimental work to test hypotheses about which factors most influence bycatch rates, and to explore ways of managing fishing activities and/or improving gear design to minimize the incidental capture of species of conservation concern, whilst ensuring the viability of the fisheries concerned.

Introduction

The incidental capture or bycatch of non-commercial species in fishing gear is widely recognized as an important threat to the conservation status of many animal populations (Read et al. 2006; Žydelis et al. 2009, 2013; Gilman et al. 2010; Reeves et al. 2013). Air breathing taxa including birds, turtles and marine mammals are particularly vulnerable because of their requirement to surface at regular intervals. Among broad fishing gear types, gillnets represent a particular concern because they are known to be associated with relatively high bycatch mortality of all three of these taxa. Here we include in the general term 'gillnet' several types of static fishing net, including set or drifting gillnets, entangling nets and trammel nets.

Gillnets are sheets of netting, constructed typically with thin nylon twines, that are held open by a rope frame consisting of a floatline along one side to provide buoyancy and a weighted leadline along the opposite side (Figure 2a). Individual panels or sheets of netting are usually 30m to 100m in length, but it is common practice to combine several panels along a longer length of floatline and leadline, making a multi-panel “fleet” of nets the operational unit. Fleets vary in length from a few hundred meters to over ten kilometers. Fleets are left in the water for varying lengths of time (the soak time) to catch animals that swim into them. Depending on the specific net configuration this process may involve meshes wedging behind a fishes operculum (known as “gilling”), entanglement of non-fusiform species by the teeth or surface spines/protuberances in loosely rigged or slack netting or “bagging” in multi-panel trammel nets.

Despite this apparent simplicity, several features of gillnet design can be controlled or modified to maximize the catch of particular target species or to improve the selectivity of certain size classes. These include characteristics such as mesh size, twine type and diameter, net panel manufactured height, actual fishing height (controlled primarily by the amount of buoyancy) and hanging ratio. The hanging ratio is the ratio of the length of the net panel as rigged on its rope frame to its maximum stretched length. The tangling effect of the net is increased by reducing the hanging ratio (typically to around 0.3) and often by using minimal buoyancy. Aspects of fish size, shape and behavior are all taken into account when designing net configurations to maximize capture probability (Hamley 1975; Fridman 1986).

The use of thin, flexible (soft) and transparent fibers in nylon netting materials has greatly increased the fishing efficiency of gillnets since the 1950s (von Brandt 1984) . These same properties are likely to make bycatch of non-target species more likely too. Numerous studies on the bycatch of mammals, turtles and birds in gillnets have been conducted since this issue was first highlighted in the 1970s (Tull et al. 1972; Lear & Christensen 1975), but most of the literature is focused on demonstrating conservation implications. Potential mitigation measures aimed at resolving bycatch problems in gillnets have been studied, though less frequently, while efforts to understand the underlying causes have attracted relatively little attention thus far. The focus on mitigation is problematic because many of the more obvious mitigation measures have already been tested, and future progress is likely to increasingly depend on improving our understanding of the underlying factors (i.e. gear design, environmental variables, animal behavior etc.), that increase the probability of bycatch. Furthermore, most mitigation studies thus far have been focused on one taxon at a time, even where two or more taxa may be impacted by the same gear type in the same geographical area.

Our primary objective in the present paper is to synthesize the results from the studies that we have reviewed in order to identify the factors most frequently cited as contributing to the bycatch of protected species. This analysis is intended to help focus future work on those aspects of the bycatch problem that might most usefully be addressed in order to develop mitigation measures across taxa. To that end we consider the possible practical utility of each of the factors that we identify as being potentially relevant. In addition we have analyzed the literature on gillnet bycatch with a view to understanding how this has developed over the past few decades, which taxa have been most or least examined with respect gillnet bycatch and to what extent studies of bycatch mechanisms are reported in the literature.

Methods

We used four bibliographic data sources to identify studies that relate to gillnet bycatch of marine mammals, birds and turtles. These were Web of Science (Biosis), Scopus, Aquatic

Science and Fisheries Abstracts (ASFA) and Google Scholar. Google Scholar was interrogated using Publish or Perish Software (Harzing 2007). We also used references from other published papers and our own bibliographic resources to identify relevant papers.

We used the same search terms in all four bibliographic sources. We made queries by major taxon and broke the results down by year. Search terms by taxon were “marine mammal”, “cetacean”, “seal”, “dolphin”, “pinniped”, “porpoise”, “sirenia”, “seabird”, “sea bird”, or “turtle”. To address gillnet bycatch related studies we used the terms “gillnet”, “bycatch” or “entanglement” or “by-catch” or “incidental catch”. Exploratory tweaks of these terms did not make a lot of difference to the results and while we may have failed to exhaust all of the relevant literature, we are confident that we have captured the vast majority of the relevant studies available through these sources. All four search returns were sorted or interrogated by year.

We compared results between bibliographic databases to investigate how well the studies in this field have made it into the ‘mainstream’ literature, to compare the volume of work in each taxonomic group and to look for trends in research output.

We identified studies that examined causal factors underlying bycatch. These included studies that were deliberately designed to investigate potential mitigation measures, as these usually test a mitigation measure or modified gear against control or unmodified gears. Mitigation trials therefore help elucidate the role or importance of a specific factor in driving bycatch rates whether the result is deemed positive or not.

We also used several recent major reviews of gillnet bycatch in each of the three taxa, papers cited therein and our own knowledge to track down studies not necessarily reported through the bibliographic sources that we queried.

The main focus of the work here was to identify factors associated with fishing practices, fishing gear, or non-target animal behavior in relation to fishing gear, that have been correlated with bycatch rates, as well as those that have been shown to be independent of bycatch rates. We combed through the results of the three bibliographic databases, and the first 1000 (if available) returns from Google Scholar for each of the three taxa. We used background knowledge, titles and abstracts to identify papers relevant to our research focus. Some cited papers could not be found online. We also identified papers from our own knowledge and from a few key reviews, including a web-based database on bycatch mitigation measures that have been tested (Werner et al. 2006). We identified these factors from the available literature and were aided by statistical analyses of fisheries where analysts had listed properties that they had been able to include in statistical models to describe bycatch rates.

We have tabulated all of the factors that we identified, and scored them according to whether we found evidence of any correlation with observed bycatch rates for each of the three main taxa (mammals, birds, turtles). Evidence of correlation did not include any speculative suggestions reported in research studies.

We then went through all of the identified factors and made a judgement, based on our understanding of fishing operations, as to how useful they might be in attempting to derive mitigation strategies to minimize bycatch of protected marine species.

Results

Bibliographic Analyses

We found a wide disparity in the number of studies reported by the four bibliographic data sources that we used (Table 1). As expected, Google Scholar yielded many more studies than any of the three bibliographic databases. This is because Google Scholar searches a wider selection of sources including conference proceedings, theses, books and most importantly grey literature – or informally published documents such as technical reports whereas the bibliographic databases mainly relate only to established peer-reviewed journals. Google scholar also searches the entire text of a paper and does not focus solely on the keywords, abstracts and title as do the main bibliographic database searches. In this field it would appear that a great deal of work is conducted and reported on outside the formal academic literature.

Among the three bibliographic databases there was a low degree of congruity- with only about 10% of publications being identified by all three. Aquatic Sciences and Fisheries Abstracts generated the greatest number of returns, as this database focuses on aquatic sciences, but less than 20% of the ASFA references were in common with either of the other bibliographic databases' returns.

Comparing the three taxa, all four searches indicate that more work on gillnet bycatch has been directed at marine mammals than the other two taxa. Google Scholar and ASFA produced more returns for turtles than seabirds, whereas there was little difference between these two taxa for the other two bibliographic databases. For all three taxa the greatest increase in published work appears to have occurred between about 1995 and 2008, while there may have been a levelling off in the annual number of published studies in more recent years (Figure 1, for Google Scholar). Among marine mammals almost twice as many studies were returned by Google Scholar for cetaceans (5200) than for pinnipeds (pinnipeds, seals or sea lions: 2850), with only 115 studies on sirenian (dugong or manatee) bycatch in gillnets.

Google scholar produced too may search returns to explore in detail. Publish or Perish software only returns the first 1000 records, which Harzing (2007) holds are likely to be the 'most relevant' to the query, and indeed it seems clear that documents where the search terms appear in the title rather than just the main body of text are closer to the top of the Google Scholar search returns. Overall Google Scholar identified over 20,000 documents relating to the search terms, too many to examine in any detail, but a useful source for rapid screening. For the returns from the three bibliographic databases we identified over 660 unique papers that relate to gillnet bycatch of the three taxa of concern. From all sources we found 62 studies where evidence of a link between one or more gear factor and bycatch rate was reported, but only 22 of these studies (35%) were listed among 662 studies identified by the major bibliographic databases.

Our results indicate that there has been a great deal of research attention to the issue of gillnet bycatch over the past 30 years, with more attention paid to marine mammals than to other taxa, but studies of gillnet bycatch for all taxa have been poorly reported in the primary literature, and very few of the thousands of studies conducted appear to have examined the underlying causes of bycatch. The majority of such work is to be found in research reports, government laboratory memorandums, workshop proceedings and graduate theses which are poorly covered by the main bibliographic databases.

Factors Related to Bycatch rates

Twenty eight candidate factors were identified from the papers that we reviewed. These may not represent a comprehensive list, but all can be clearly linked to potential reasons why they might have a significant impact on bycatch rates and all have been addressed by one or more of 62 studies that we identified (see Supplementary Material for a fuller discussion). Some factors are clearly correlated with one another, but we have still treated them separately in order to try to understand underlying casual mechanisms for bycatch. The twenty eight candidate factors can be divided into four categories. Environmental factors include things like the weather, water temperature and turbidity, as well as season. Operational factors include those aspects of fishing that can be controlled on a trip by trip basis, such as location or time of day. Technical factors include features of the gear involved, such as the mesh size or hanging ratio, while biological factors include behavior and physiological constraints of the bycaught animals themselves.

The twenty eight identified factors are listed together with a brief explanation as to how they might influence bycatch rates in Table 2. A more detailed description of each factor and the evidence for correlation with bycatch rates is available as a bibliography in Supplementary Material. Table 2 about here

Although we identified 62 studies that showed evidence of a correlation with bycatch rates, or the clear absence of any correlation, there are undoubtedly other studies that we did not locate, especially in the grey literature, and our total does not necessarily include all the studies that have demonstrated the same effect. Thus we did not distinguish between studies that have been conducted just once to demonstrate an effect and those that have been repeated many times. For example, acoustic signals have been shown to reduce the bycatch of harbor porpoises in 11 separate published studies (Dawson et al. 2012), but this is given no more weight in our table than a single study that has shown that some bird bycatch can be reduced with the use of acoustic deterrents (Melvin et al. 1999a).

At least twenty four factors have been linked with elevated bycatch rates. Associations with bycatch that have been demonstrated have been summarised (Table 3) for each of the three taxa of concern. In most cases the link between the influencing factor and bycatch rates has been established either through statistical modelling of a multi-factorial bycatch dataset, or by direct comparisons of observed bycatch rates between different operational, environmental or technical factors. In a minority of cases the correlation has been demonstrated through dedicated mitigation trials, where a postulated mitigation measure has been applied in a fishery and controlled observations have been made of modified and unmodified fishing practices.

Four symbols are used in Table 3: a tick/check symbol is used where some correlation has been demonstrated; an ‘x’ symbol is given where the lack of a correlation has been demonstrated. We have used a “?” where studies have been equivocal or contradictory (between two or more studies) and we have indicated a blank “-” where we found no evidence of any correlation having been tested. We have only included studies where we were convinced a robust comparison or assessment had been made, and have not included speculative suggestions of possible causal links, though these were taken into account initially when creating the list of potential categories.

Among the 28 factors listed, three have been shown to influence the bycatch rates of all three taxa. These are *water depth*, *mesh size*, and *net height*. This suggests that they may be worth pursuing further if cross taxa mitigation measures are to be identified and developed. Conversely, *twine color* has been shown to have no effect on bycatch rates of two of the three taxa, suggesting this may not be a priority for further cross-taxa work. There are 11 other factors that have been shown to be correlated with bycatch of two of the three taxa, any of which might also be usefully explored further.

Discussion

Our bibliographic analysis showed a rapidly increasing trend in the number of published studies on the bycatch of mammals, birds and turtles in static net fisheries between the early 1990s and 2008, and indicated that the main focus of most of those studies was on demonstrating conservation concerns. The surge of research interest seen during that period may now be beginning to slow, though the issue of bycatch remains of key importance to the conservation of many marine species(Read et al. 2006; Žydelis et al. 2009; Gilman et al. 2010; Reeves et al. 2013) .

Gillnet fisheries are a relatively low cost and efficient method of fishing and are widely used among small scale fisheries throughout the world (Valdemarsen 2001). The ubiquitous nature of these fisheries, their associated societal benefits and known wider ecological effects raise important questions on how to balance food security, employment, economic activity and equitability against environmental concerns. Management efforts clearly need to consider all of these factors to find suitable and acceptable ways of minimizing the impacts of gillnet fishing on vulnerable taxa whilst maintaining, or even enhancing, the benefits those fisheries provide.

The main aim of this study was to identify and review the work that has previously been conducted to understand the underlying causes or mechanisms of bycatch. There are relatively few such studies when compared to the volume of literature that simply documents or quantifies bycatch levels. Much of the relevant work is not available in the mainstream literature and may therefore be obscure to researchers or policy makers who are not directly involved in the research.

If it is possible to better understand the causes of bycatch, then it should provide a basis for refining fishing methods and mitigation measures to reduce the bycatch of vulnerable or protected species. The immediate challenge for developing acceptable mitigation measures is to modify technical or operational factors to produce useful reductions in bycatch while simultaneously maintaining target catch rates. Depending on the jurisdiction and the local societal concerns about vulnerable species conservation, some commercial catch reduction may be tolerable if bycatch mitigation can be successfully achieved.

A ‘useful reduction’ in bycatch also needs to be considered conceptually. For highly vulnerable or depleted species a ‘useful reduction’ might require the complete or near complete elimination of bycatch, which may involve the introduction of draconian regulations. For less vulnerable species the potential benefit of any likely bycatch reduction needs to be judged against conservation goals and the costs (to management and industry) from the outset. It is important therefore to quantify what level of bycatch reduction is required and how likely this is to be achieved by specific gear modifications or new management measures.

Agreed ‘useful reductions’ in bycatch levels are only of use if they can actually be maintained over time. It has been noted, for example, that despite observed 90% reductions in bycatch rates of porpoises associated with the use of pingers in scientifically designed trials, longer term efficacy in commercial fisheries can be lower as fishers’ enthusiasm for the added workload (such as battery changing) diminishes (Dawson et al. 2012). For bycatch mitigation measures to work in practice, rather than in controlled experiments, they must be easy to assimilate into normal fishing practices and effective long term compliance also requires the fishing community to be convinced of their utility (Poonian et al. 2009).

Among the factors this analysis has identified some clearly represent more practical routes to mitigation than others and we discuss some potential avenues for further mitigation research efforts below.

Environmental Factors

While generally impossible to modify or control directly, environmental factors might be useful in certain circumstances if fishing activity could be restricted in known and/or predictable conditions when or where bycatch is most likely to occur. The most tractable example could relate to water depth. For example, prohibiting bottom set net fishing from depth zones where bycatch rates are highest might provide a useful means of delimiting 'protected areas' for some species, though this approach would not necessarily work across different species and could therefore become excessively complicated or restrictive if several species required different measures with the same general area.

Nevertheless, this approach has already been adopted in some areas to protect seabirds (Forney et al. 2001). Delineating depth zones of highest bycatch will require detailed study and systematic assessments of bycatch rates in individual fisheries and it is questionable if observed results from one area would be applicable to fisheries in other areas.

Restrictions to fishing based on some other environmental factors are conceivable even if examples are lacking.

Operational Factors

Time and area closures are already used where aggregations of vulnerable species are known to occur. Diurnal restrictions are used to protect several sea bird species in Washington State for example (Washington Department of Fish and Wildlife 2014), while area-based restrictions have been used widely to protect cetaceans from bycatch (NMFS 1998; Gormley et al. 2012). It is not clear, however, whether this approach might work for more than one taxon at a time in the same area.

Among other operational factors, soak duration appears to affect bycatch rates of at least two taxa, but this is unsurprising because the probability of bycatch occurring per haul is likely to increase with longer soak times. Shorter soak times would therefore probably reduce bycatch rates per haul, all other things being equal, but would likely have the same or similar impact on fish catches. Unless there is a less than linear relationship between soak time and target fish catch, or a greater than linear relationship between soak time and bycatch, reducing soak times is unlikely to be a useful mitigation approach on its own. It should be noted that soak time is usually linked to a diurnal fishing pattern, so it will usually be difficult to separate effects of soak time per se from diurnal changes in behavior or perception ability of the bycaught species.

Altering vessels' discarding strategies seems a less promising avenue at present, although for seabirds this is an area that may justify some further work. A number of non-diving sea bird species have been reported from bottom set nets which suggests capture when the net is close to the surface (i.e. either during hauling and shooting operations) and near the boat which suggests some attraction of surface feeding birds to the vicinity of the boat at those times. Indeed, the use of baited gillnets has been associated with elevated bycatches of shearwaters (Hatch et al. 2015) presumably due to attraction, so there may be some scope for bycatch reduction here by modifying the bait in this very specific situation.

Target species has not been explicitly linked to any increase in bycatch rates of mammals, birds or turtles, but this is probably due to the fact that the target species is really just a function of other more specific and influential variables, such as mesh size or location.

Technical Factors

Technical factors contain more promising areas for further research. Mesh size and net height were both identified as important correlates of bycatch rates for all three taxa. Mesh size has already been regulated in at least one area to minimize turtle bycatch (Murray 2009), but as a widespread measure it is probably not compatible with the idea of maintaining commercial fish catch levels, and dramatic restrictions on mesh size may effectively amount to a fishery closure in some situations. However fishery specific restrictions if applied appropriately may be preferable to a closure of all net fisheries in an area where bycatch is a particularly important concern. Net height may be a more tractable factor to address bycatch whilst maintaining fish catch levels, at least in some fisheries. Trials in the US suggest there is considerable scope for this approach (Price & Van Salisbury 2007; National Marine Fisheries Service & Atlantic States Marine Fisheries Commission 2013), assuming sufficient experimental work can be done to identify the optimal net height (see illustration in Figure 2c).

Other technical factors that appear to warrant further investigation include altering the fishing depth, twine diameter and twine material, the floatline type and the use of tie-downs. Fishing depth is most useful in surface driftnet fisheries, where subsurface deployments of drift nets (Figure 2b) can reduce bycatch of protected species whilst maintaining target fish catch (Hembree & Harwood 1987; Hayase & Yatsu 1993). This is an approach that needs to be tested on a fishery by fishery basis, as results will depend on the behavior of both the target and non-target species in each situation. It is possible that the same approach could be tried for some demersal species, by using rope legs to hold the net off the bottom (Figure 2b) as is done in some areas to minimize damage to the commercial catch by benthic scavengers (Arkley 1989). This approach will only work if there is sufficient difference in the vertical distributions or behaviors of the target and the non-target species.

Twine diameter may be helpful in some cases where the non-target species could be expected to break free from the twines concerned (NMFS 1998; López-Barrera et al. 2012). This approach would be most likely to succeed for larger more powerful animals like marine mammals and some turtles, and less likely to work for birds which are generally closer in weight and swimming strength to the target species. Furthermore, thinner twines will result in more mesh breakages which will affect gear longevity and therefore replacement costs, and may affect the target fish catch rates as the gear's catching efficiency is affected.

Twine material or twine type have been subject to limited experimental trials, but the use of nylon impregnated with metallic compounds (iron oxide or barium sulfate) has resulted in lower bycatch rates of birds and mammals in some studies but not in others (Trippel et al. 2003; Larsen et al. 2007; Bordino et al. 2013). Some of the mechanical properties of fishing twines may prove a useful means of reducing bycatch rates, provided target fish catch rates can be maintained. This is an area where further work is needed to try to explain the apparently contradictory results of trials to date whereby some metal impregnated nylon nets have led to decreased bycatch rates, while others have not.

Floatline type appears to have some influence on bycatch rates, though the extent has not been fully quantified (Palka 2000; Sea Mammal Research Unit et al. 2001). The underlying reason for this apparent effect is also unknown, but may be because different floatline types affect the way the net meshes behave underwater, or because some floatlines are more or less detectable to some species. Again this is an interesting area but more research is needed to understand what role floatlines may have in determining the probability of bycatch among birds, turtles and mammals.

The use of tie-downs has been correlated with differences in bycatch rates of mammals and turtles (NMFS 1998; Peckham et al. 2009), but not yet for birds. The optimal use of tie-down (which are probably only useful for a few target fish species such as flounders) has yet to be determined, and further research here is clearly needed.

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Behavioral and physiological factors

Among behavioral and physiological factors, several avenues of research look promising. Visual deterrence or alerts have been subject to only limited research in the context of gillnets. Martin and Crawford (2015) suggest that a visual approach could be effective for all three taxa, and advocate the use of black and white stripes or squares of around 60mm width in patches inserted among the net meshes like checkered flags, to make the most of the visual acuity of birds, mammals and turtles by providing a contrast in low light conditions. The use of lights on nets also appears to show some promise, notably for birds and turtles, but this has not yet to our knowledge been tested for mammals. However, Martin and Crawford (2015) warn that solutions using visual stimuli should not disrupt the dark adapted state of the animals' retinas as this would impair visual acuity for some period after exposure and could therefore make matters worse.

Acoustic deterrence has been trialed and tested many times with positive results in relation to cetacean bycatch (Dawson et al. 2012), but only once for seabirds (Melvin et al. 1999b), whose sub-surface hearing abilities are poorly understood. Clearly, if acoustic deterrent measures are successfully used for cetaceans, their effects on other groups should be explored in more detail.

Conclusions

It is clear that there is no obvious single factor that provides the key to minimizing bycatch of all three taxa of concern. Nevertheless some factors (such as water depth, net height, mesh size, floatline type) have a marked influence on the bycatch rates of more than one taxon, and these areas warrant much more detailed work, including more comprehensive sea trials and experiments to test their effects on bycatch in situ. Sea trials are relatively expensive to undertake, but given the absence of any 'silver bullet' solution to this issue, more work must be undertaken if vulnerable species bycatch is to be addressed in a balanced and productive manner. Experiences from around the world suggest that progress is likely to be slow and incremental, meaning patience will be required from those with an interest in the issue.

The relative scarcity of published work focused on the underlying causes of one of the most serious conservation threats to air breathing marine vertebrates is itself a cause for concern. Further work to examine how fishing practices, technologies and animal behavior influence bycatch are urgently required, while previous and ongoing studies need to be made much more readily available through publication in the mainstream literature.

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Table 1 Numbers of publications returned using the same search criteria on gillnet bycatch for three taxa, from four bibliographic data sources

Reference Source	Mammals	Birds	Turtles	All [1]
Google Scholar	6700	3700	4760	15160
ASFA	351	71	132	554
Biosis	311	71	74	456
Scopus	94	42	49	185

Table 2 A list of Potential Factors that may be correlated to Protected Species Bycatch rates

Factors that might influence bycatch	**Rationale for possible influence on gillnet bycatch rates**
Environmental factors	
Turbidity	Water clarity may affect ability to detect net
Wind /weather	Poor weather may increase turbidity or increase net movement
Water temperature	May change animals activity patterns or physiology
Water depth	Linked to location - but more specific - diving ability affects vulnerability

[1] This total will include duplicates where returned papers discuss more than one taxon

State of tide	Tidal factors may change both animal or net behavior
Water current	May change net behavior or make avoiding a net more difficult
Operational factors	
Fishing location	Locations that are associated with high animal density may be a concern
Time of day	Some animals may be more active at certain times of day; net visibility
Month / season	Seasonal changes in distribution or behavior of bycatch species
Target species	May be an association between the target species and the bycaught species
Soak duration	Long soak times may influence probability of capture or death
Offal discharge	Fish or offal discarding may encourage association with fishing gear
Technical factors	
Mesh size	Mesh size usually has a profound effect on capture probability of fish
Net length	Longer nets more likely to catch more animals
Net height	Higher nets able to entrap animals further from the seabed, larger net area
Depth set	Dive and feeding depth of animals will influence probability of capture
Twine diameter	May influence chances of the animal getting caught or not
Twine color	Some colors may be more detectable to some animals
Twine type	Monofilament claimed to catch more than other twine types
Hanging ratio	More entanglement likely when net is more 'bunched' on its rope frame
Floatline type	Different float types will alter the net configuration underwater
Tie-down	Tie-downs will reduce net height but also increase bagging of the net
Setting direction	Along shore or perpendicular may interact with swimming direction
Lead line	Heavy lead lines may make escape or surfacing more difficult

Behavioral and Physiological factors	
Light	Underwater light may highlight danger or scare animals away
Chemoreception	Chemical stimuli may deter animals from vicinity of netting
Acoustic	Acoustic warning or averting stimuli may keep animals away from net
Other behavior	Other ways behavior may influence or be manipulated e.g. dummy sharks

Table 3 Factors identified as correlated with bycatch rates by taxa

Factors that might influence bycatch	**Possible link to bycatch rate?**		
Environmental factors	**Mammals**	**Birds**	**Turtles**
Turbidity	-	-	-
Wind /weather	□	□	-
Water temperature	-	-	□
Water depth	□	□	□
State of tide	-	-	-
Water current	-	-	-
Operational factors			
Location	?	□	□
Time of day	-	□	-
Time of year / season	□	□	-
Target species	x	-	-

Soak duration	□	-	□
Discard discharge	-	?	-
Technical factors			
Mesh size	□	□	□
Net length	□	-	-
Net height	□	□	□
Depth set	□	□	-
Twine diameter	□	-	□
Twine color	x	x	-
Twine type	□	□	-
Hanging ratio	x	-	-
Floatline type	□	-	□
Tie-down	□	-	□
Setting direction	x	-	-
Lead line	x	□	-
Behavioral and Physiological factors			
Vision and Light	-	□	□
Chemoreception	-	-	-
Acoustic	□	□	-
Other behavior	?	□	?

Legend

Figure 1 Trends in the numbers of papers published by year for gillnet bycatch for various taxa: Google Scholar

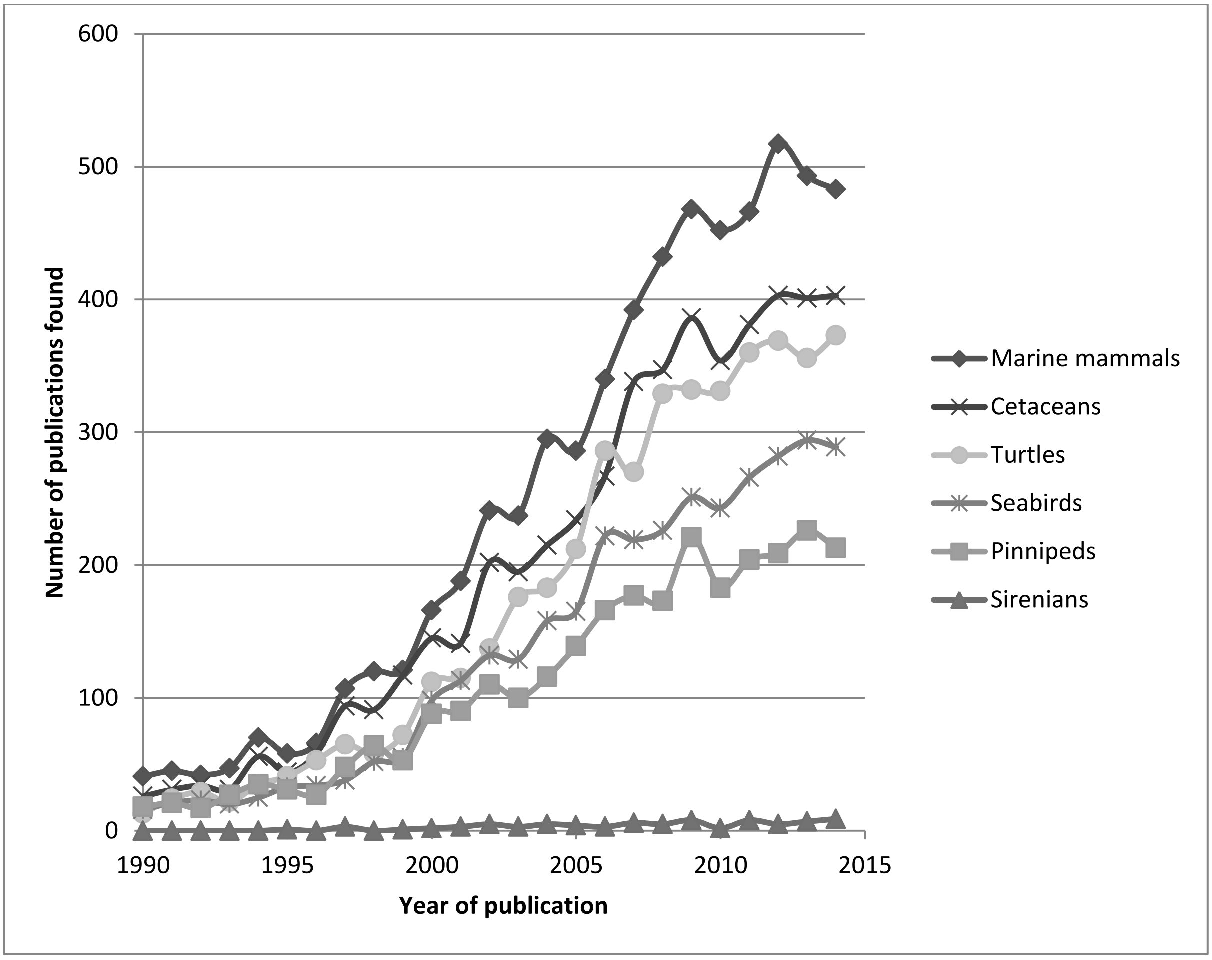

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Figure 2 Top (1 figure), middle (4 figures) and bottom panels (3 figures). Gillnet schematic diagrams:

Figure 2a A schematic representation of a (bottom set) gillnet showing main components

Figure 2b Ways in which the fishing depth of a gillnet can be modified. Top left – standard drift gillnet; Top right sub-surface drift net; Bottom left standard bottom set gillnet; Bottom right off-bottom set gillnet