The use of time/area closures to reduce bycatches of harbour porpoises: lessons from the Gulf of Maine sink gillnet fishery

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ABSTRACT

In 1994, the United States National Marine Fisheries Service (NMFS) implemented a series of time/area closures for the Gulf of Maine sink gillnet fishery to reduce the bycatch of harbour porpoises (*Phocoena phocoena*). The present study evaluates the effectiveness of the Mid-Coast closure area, implemented during November 1994. Rates of porpoise bycatches are analysed prior to, during and after the closure. In addition, individual vessels are tracked and the spatial distribution of fishing effort examined to determine how fishermen responded to the closure. The highest bycatch rate occurred in September in the Mid-Coast region, well before the closure. During November, fishermen concentrated much of their effort adjacent to the closed area in unrestricted waters, where bycatch occurred. The Mid-Coast closure was not in place for a long enough period, nor was it large enough, to be effective in reducing bycatch rates of harbour porpoises. The failure of the Mid-Coast closure is attributed to temporal and spatial variation in patterns of bycatch rates, and to the displacement of fishing effort and porpoise bycatch outside the closed area.

KEYWORDS: HARBOUR PORPOISE; INCIDENTAL CATCHES; GILLNETS; EFFORT; CONSERVATION; REGULATIONS; ATLANTIC OCEAN

INTRODUCTION

The bycatch of non-target species has become a focal point of current fisheries management (Alverson *et al.*, 1994). The incidental capture of non-target organisms may have significant effects on the dynamics of affected populations and on the structure of food webs and ecosystems (Crowder and Murawski, 1998). Both regulatory and gear-selectivity solutions have been used to address the impacts of fishery (Rulifson *et al.*, 1992) and non-fishery bycatch species, such as turtles (Crowder *et al.*, 1995), seabirds (Bergin, 1997) and marine mammals (IWC, 1994). For example, changes to fishing gear and practices reduced the mortality of pelagic dolphins in the eastern tropical Pacific purse seine fishery for yellowfin tuna by more than two orders of magnitude between 1972 and 1997 (Joseph, 1994).

Time and area closures have been used to reduce the bycatch of non-target species. According to Murawski (1994), 'the objective of area/time management is to take advantage of naturally occurring variations in the degree of co-occurrence between target and bycatch species'. Murawski (1994) considered that to be effective, time/area closures should result in consistently lower bycatch rates, be economically viable for the fishery and be successfully enforced. Time/area closures have been used to reduce the bycatch of both fish (Parsons, 1993; Cadrin *et al.*, 1995; Bishop and Brodie, 1997; Pastoors *et al.*, 1998) and marine mammals (Dawson and Slooten, 1993), although evaluation of the success or failure of these areas has been limited (Bishop and Brodie, 1997).

The pressure to reduce bycatches of marine mammals in US commercial fisheries intensified following amendments to the Marine Mammal Protection Act (MMPA) passed in 1994. These amendments require that anthropogenic mortality of marine mammals not exceed removal levels, referred to as the 'Potential Biological Removals' (PBR), designed to meet the management objectives of the MMPA (Wade, 1998). The MMPA further mandates that, when bycatches exceed PBR for a given stock, a 'take reduction plan' must be developed. Such a plan describes means by which the magnitude of bycatches will be reduced to below PBR. Consequently, managers and stakeholders are under considerable pressure to find ways to reduce the bycatch of marine mammals while maintaining the viability of affected fisheries.

One of the largest bycatches of marine mammals in US fisheries is the incidental capture of harbour porpoises (*Phocoena phocoena*) in the New England multispecies sink gillnet fishery (Bravington and Bisack, 1996; Bisack, 1997). The mean annual mortality of harbour porpoises in this fishery between 1992 and 1996 was 1,460, more than three times the PBR (Waring *et al.*, 1999). Demographic models suggest that these bycatches may not be sustainable (Caswell *et al.*, 1998).

To reduce the bycatch of harbour porpoises, the NMFS, in consultation with the New England Fishery Management Council (NEFMC)[1], implemented a series of time/area closures for the New England multispecies sink gillnet fishery in 1994 (Fig. 1). This paper examines patterns of bycatch and fishing effort affected by the Mid-Coast closure implemented from 1-30 November 1994. This closure was chosen because it was instituted in the area of highest porpoise bycatch and, consequently, considerable data were available on fishing effort and bycatch in this region. The Mid-Coast closure was designed to achieve the greatest reduction in the bycatch of harbour porpoises with the least disruption to fishing practices, based on a spatial analysis of observed porpoise mortalities and gillnet fishing effort in

[1] The NEFMC is one of eight regional councils established under the US Magnuson-Stevens Fishery Conservation and Management Act. It comprises 17 voting members, including the Regional Administrator of the National Marine Fisheries Service, the principle state official with marine fishery responsibility (from the representative New England states), and 11 members who are appointed by the governors of the New England states. These 11 members are primarily from the fishing industry, though some represent conservation groups. There are also 4 non-voting members from the US Coast Guard, US Fish and Wildlife Service, US Department of State and the Atlantic States Marine Fisheries Commission.

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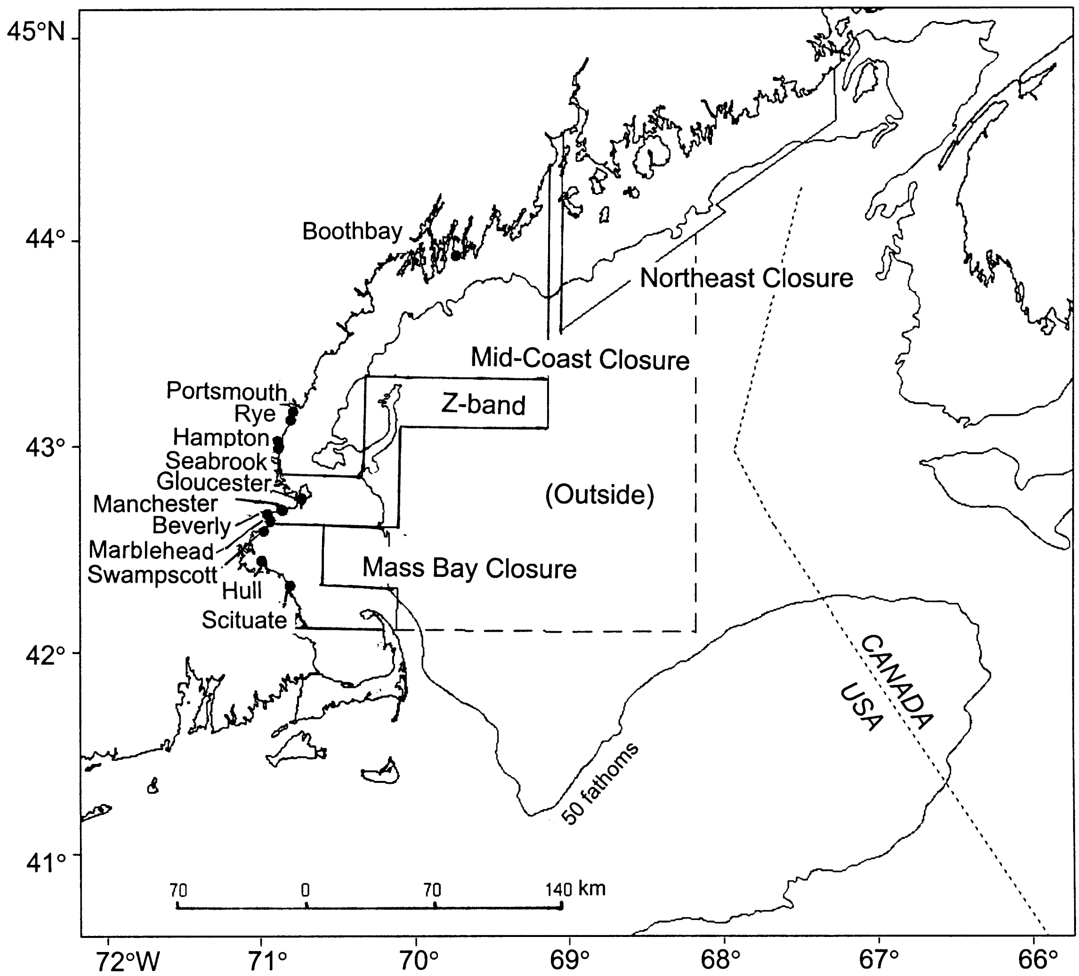

Fig. 1. Time/area closures in the Gulf of Maine for the New England multispecies sink gillnet fishery, fall 1994. The 'Outside' area and 50 fathom (300m) isobath are also shown.

1991 and 1992 (New England Fishery Management Council (NEFMC), 1994). After considerable debate, it had been decided to leave open the 'Z-band' area, bordering the Mid-Coast closure to the south and east, to minimise the area from which fishermen would be excluded. The NEFMC acknowledged that fishermen could move into the Z-band during the closure month, potentially offsetting any reduction in bycatch achieved in the closure area (New England Fishery Management Council (NEFMC), 1994).

The effectiveness of the Mid-Coast closure in reducing the bycatch of harbour porpoises in the New England sink gillnet fishery is assessed by examining whether the spatial and temporal distribution of bycatch rates coincided with the closure. Tracks of individual vessels and the spatial distribution of fishing effort are also examined to determine how fishermen responded to the closure, as a first step in understanding how time/area closures affect fishermen's behaviour. Finally, the effect of the closure on fishermen from different homeports in the New England region is examined. We hope that lessons learned from this case study will prove valuable in the design of time/area closures in other regions where small cetaceans are taken as bycatch in commercial fisheries.

METHODS

The fishery

From 1990-1995, approximately 350 vessels operated part- or full-time in the New England multispecies sink gillnet fishery, from the Gulf of Maine to southern New England (Waring *et al.*, 1999). In the autumn of 1994, the fishery employed nets with 6-10 inch (*ca* 15-25cm) monofilament mesh strung between an upper float line and a weighted foot rope, set on the sea floor at depths of up to 183m. Each net in a string was 91m in length. Most strings consisted of 5-12 nets tied together, but some boats fished up to 25 nets per string. The vertical height of each net was 3-3.6m. Nets were left to soak from 24-144 hours, then hauled back onto the boat. The fishery consisted mostly of small boats, between 11-17m, operating mainly on one-day trips. Fishermen targeted Atlantic cod (*Gadus morhua*), pollock (*Pollachius virens*), monkfish (*Lophius americanus*), spiny dogfish (*Squalus acanthias*) and other groundfish. The primary target species of the fishery in the autumn of 1994 were Atlantic cod, pollock and mixed groundfish (85% of observed effort).

Data sources

The Northeast Fisheries Science Center Observer Program (National Marine Fisheries Service, Woods Hole, MA) supplied data collected by observers working on sink gillnet vessels from September to December 1994. Observers are placed on a random sample of vessels in this fishery to estimate the bycatch rate of harbour porpoises and other marine mammals (Waring *et al.*, 1999). All observed hauls north of 42° and west of 68° were used in the analysis. At each haul (when nets were brought onboard) observers recorded position, presence or absence of harbour porpoise bycatch, soak duration, number of nets in the string, depth at which the string was set, mesh size and target species.

Also examined were data from a scientific experiment carried out independently of this study, during the Mid-Coast closure in 1994. Fifteen commercial vessels participated in the experiment (referred to as 'experimental' vessels in this study), conducted from 18 October to 15 December 1994. Fishermen from Boothbay Harbor (Maine); Portsmouth, Rye, Hampton and Seabrook (New Hampshire); and Beverly (Massachusetts) chose to participate. The vessels were allowed to fish in the closed area provided they used acoustic alarms or 'pingers' on their nets and conformed to other experimental restrictions (see Kraus *et al.*, 1997 for an analysis of the effectiveness of acoustic alarms in reducing bycatch of harbour porpoises). Each vessel that participated in the experiment had an observer on board every day. Fishermen placed either active (emitting sound) or control (silent) alarms on their nets; the treatments were assigned randomly and neither fishermen nor observers knew whether the devices on their nets were active or controls. Only those hauls with control (silent) alarms were examined in the current study so that all nets in the data set shared the same characteristics. Twenty-five porpoises were caught in the Mid-Coast area in gillnets with control alarms, indicating that the experiment did not displace porpoises from the area (Kraus *et al.*, 1997).

Fishermen who participated in the experiment could set their nets either inside or outside the closed area, while those that did not participate were obliged to comply with existing regulations. The experiment, therefore, provided an opportunity to compare the spatial distribution of fishing effort between vessels that were affected by the closure and those that were not. In addition, the experiment provided an opportunity to examine potential bycatch of harbour porpoises had the closure not been in effect.

The locations of hauls were plotted in ARC/INFO version 7.0. The New England Fishery Management Council provided coordinates of the closure areas (New England Fishery Management Council (NEFMC), 1994). Fishing effort and closure boundaries were then overlaid on Northeast coastline and depth contour coverages in an Albers Conic Equal-Area map projection. These Geographic Information System (GIS) layers enabled us to: (1) assess bycatch rates before, during and after the closure period; and (2) examine how fishermen responded to the closed area.

Statistical analysis of bycatch rates

Separate bycatch rates were calculated for three areas – Mid-Coast (the closed area), Z-band and Outside (west of 68°W and north of 42°N to the closure and Z-band borders) for September, October, November and December 1994. Strings equipped with active pingers were excluded from all calculations. Bycatch rates (reported as means with associated standard errors) were standardised for string length and soak duration and calculated as the number of porpoises taken/string length(km)/days soaked.

Variation in the bycatch rate of porpoises among areas and months was examined. A preliminary analysis indicated that the capture of porpoises by the same net were not independent. This could occur, for example, if porpoises travelled in groups. To avoid the problem of dependence, the probability of at least one capture was modelled. In our model, $Y_{ijk} = 1$ if haul (k), in area (i), and month (j) resulted in a porpoise capture, otherwise $Y_{ijk} = 0$. The probability of Y_{ijk} is defined as:

$$p_{ijk} = 1 - \exp(-L_{ij} * x_{ijk})$$

where:

p_{ijk} = the probability of capturing a porpoise in haul k, area i and month j, for a 1km string with a 1 day soak duration;

L_{ij} = the parameter to be estimated that depends on i (area) and j (month);

x_{ijk} = the product of total net length (km) and soak duration (days).

The following sequence of models were tested:

H_0: $L_{ij} = L$ (probability of bycatch did not depend on area or month);

H_1: $L_{ij} = L_j$ (probability of bycatch depended on month but not on area);

H_2: $L_{ij} = L_i$ (probability of bycatch depended on area but not on month);

H_3: $L_{ij} = L_i L_j$ (probability of bycatch depended on both area and month, but not on an interaction between area and month);

H_4: the full model, in which area and month had its own parameter.

At each step of the analysis, a likelihood ratio test of the simpler model against the more complicated alternative was performed. This involved fitting both models by the method of maximum likelihood. The likelihood ratio statistic is given by $T = 2(\log L_0 - \log L_1)$, where L_0 and L_1 are the maximised values of the likelihood under the simpler and more complicated models, respectively. Under the null hypothesis, T has an approximate chi-squared distribution with degrees of freedom given by the difference in the number of parameters under the two models.

Behaviour of fishermen

In order to examine effects of the Mid-Coast closure on fishing effort, six non-experimental vessels (those that did not participate in the experiment) were tracked to examine where fishermen chose to fish when the closure was in effect. These six vessels were chosen because they were observed in the Mid-Coast during October, indicating that fishermen on these vessels preferred this area in which to operate. These same vessels were also observed in November, allowing a comparison to be made of the number and location of hauls before and during the closure. Data from these vessels were also examined to see whether any bycatch resulted from displaced fishing effort.

To determine whether the experimental vessels could be treated as a representative sample from the overall fishing fleet, a randomisation test (Manly, 1991) was performed of the null hypothesis that the proportion of trips that were made to each of the three areas was the same for experimental ($n = 15$ vessels) and non-experimental ($n = 48$) vessels. Here, a fishing vessel is said to have made a trip to an area if it made at least one haul in the area. To eliminate the effect of the November closure, the analysis was restricted to October trips.

To determine whether the spatial distribution of fishing effort varied over time, we performed a randomisation test of the null hypothesis that the proportion of trips that were made to each of the three areas was the same during each of the four months of the study. In this case, to avoid the effect of the closure, the analysis was restricted to the experimental vessels, which were not subject to the closure.

Finally, the effect of the closure on fisherman from different homeports was examined. To do this, the proportions of traditional fishing grounds of each homeport that overlapped the Mid-Coast area were compared. Traditional fishing grounds were identified by generating a frequency distribution of the distances between a homeport and all locations where fishermen from that homeport set their nets. These measurements were based on hauls made in October, just prior to the closure. The 95th percentile of this distribution was used to estimate the typical area in which fishermen operated. This distance, which varied in size depending on the homeport, served as the size of a buffer created around each homeport in ARC/INFO. The distance buffer was then overlaid on the closure area. The area closed to fishermen was then calculated from the intersection of the distance buffer with the Mid-Coast closure. The area from which fishermen would be restricted if the Z-band had been closed in addition to the Mid-Coast was also calculated.

RESULTS

Bycatch rates

Bycatch rates varied significantly with month and area (Table 1). Under the likelihood ratio test, the full model was significant (the likelihood ratio statistic for comparing to the previous model in the sequence = 23.54, $p = 0.0006$). Thus, the probability of capturing a porpoise was dependent on both the area and month in which vessels fished. The highest bycatch rate occurred in September in the Mid-Coast region but declined to almost zero by December in this area. The highest bycatch rate in the Z-band area occurred in October.

Table 1

Observed bycatch rates of harbour porpoises in the Gulf of Maine sink gillnet fishery, autumn1994. Means are reported with standard errors in parentheses.

	Mid-Coast	Z-Band	Outside
September	0.1128 (0.0264)	0	0
October	0.0480 (0.0024)	0.0384 (0.0096)	0
November	0.0456 (0.0192)	0.0192 (0.0072)	0.0456 (0.0240)
December	0.0024 (0.0024)	0.0024 (0.0024)	0.0264 (0.0264)

Behaviour of fishermen

Six non-experimental vessels were observed fishing in both October (48 hauls) and November (18 hauls). These vessels fished primarily in the Mid-Coast during October (30 hauls). In November, these vessels shifted their effort to the Z-Band and Outside areas (9 hauls in each area). The six vessels were observed to take three porpoises in October, all in the Mid-coast area. In November, the vessels took a single porpoise in the Outside area. Thus, the closure resulted in the displacement of both fishing effort and bycatch from the Mid-Coast to adjacent areas.

There was a significant difference (χ^2 = 35.5, 1,000 randomisations, $p = 0.005$) in the spatial distribution of observed fishing effort between experimental and non-experimental vessels during October (Table 2a). Vessels participating in the experiment fished more often in the Mid-Coast and Z-band regions and less often in the Outside region compared to other vessels.

Experimental vessels displayed a significant difference (χ^2 = 15.2, 1,000 randomisations, $p = 0.000$) in the distribution of fishing effort during September, October, November and December (Table 2b). In September, experimental vessels operated more often in the Mid-Coast region and then moved farther offshore into the Z-band region as the season progressed. During November, these vessels fished more frequently in the Z-band than other areas, and less often in the Mid-Coast. Very few experimental vessels fished in the Outside area during this period. Thus, although fishermen participating in the experiment were authorised to operate in the Mid-Coast area during the closure, they chose to fish more often in the Z-band area. Compared to the experimental vessels, a higher proportion of non-experimental vessels fished in the Outside than in the Z-band area during the month of the closure (Table 3). These vessels came from homeports such as Scituate and Hull, Massachusetts, which were close to the Outside area.

Table 2

(a) Number of observed trips made by sink gillnet vessels during October 1994 in the Gulf of Maine. Vessels are divided between experimental vessels, which participated in the acoustic alarm study, and non-experimental vessels, which did not. Trips are divided among the ‘Mid-Coast’ (closed area), the unrestricted ‘Z-band’, and the region ‘Outside’ these two areas.

	Mid-Coast	Z-band	Outside	Totals
Experimental vessels	81	98	4	183
Non-experimental vessels	19	30	17	66
Totals	100	128	21	249

(b) Number of observed trips in the 1994 Gulf of Maine fall sink gillnet fishery by vessels that participated in the acoustic alarm study. Trips are divided among the Mid-Coast (closed area), the unrestricted Z-band, and the region Outside these two areas.

	Mid-Coast	Z-band	Outside	Totals
September	20	8	0	28
October	81	98	4	183
November	92	139	11	242
December	39	40	5	84
Totals	232	285	20	537

The Mid-Coast closure had disproportionate impacts on fishermen depending on their homeport (Table 4). The effect of these impacts would have been more severe and less proportionate if the Z-band had also been closed. Some fishermen would have been excluded from all of their traditional fishing grounds if the Mid-Coast had been expanded to include the Z-band. For example, most (64%) of the traditional fishing grounds of fishermen from Portsmouth was eliminated by the Mid-Coast closure; all of this area would have been lost had the Z-band been closed. On the other hand, fishermen from Gloucester, Massachusetts lost a smaller amount of their traditional fishing grounds to the Mid-Coast closure (25%). Had the Z-band also been closed, fishermen from Gloucester would have lost 56% of their traditional grounds, with the remaining 44% left open.

DISCUSSION

The closure of the Mid-Coast area to sink gillnet fishing activity in November 1994 was not as effective as it could have been in reducing the bycatch of harbour porpoises in the Gulf of Maine. Despite the imposition of this closure, as well as two others in the Gulf of Maine (see Fig. 1), the total bycatch of harbour porpoises rose from 1,400 to 2,100 between 1993 and 1994 (Bisack, 1997). This failure was mainly attributable to temporal and spatial variation in patterns of bycatch rate. In addition, displacement of fishing effort and porpoise bycatch outside the closed areas also occurred.

Temporal and spatial variation in bycatch rate

In 1994, the highest bycatch rate in the Mid-Coast area occurred during September, well before the start of the closure in November. In fact, the bycatch rate in September

Table 3

Proportion of hauls by vessels in non-experimental (non-exp) and experimental (exp) fisheries in the Mid-Coast, Z-Band, and Outside areas of the Gulf of Maine during November 1994.

		Mid-Coast		Z-band		Outside	
Homeport	*n*	Non-exp*	Exp	Non-exp	Exp	Non-exp	Exp
Beverly, MA	68	0	0.54	0	0.44	0	0.02
Boothbay Harbor, ME	60	0	0.38	0	0.62	0	0
Essex County, MA	4	0	0	0	0	1.0	0
Gloucester, MA	67	0.03	0	0.43	0	0.54	0
Hampton, NH	64	0	0.16	0.04	0.80	0	0
Hull, MA	22	0.09	0	0.09	0	0.82	0
Manchester, MA	13	0	0	0.77	0	0.23	0
Marblehead, NH	20	0	0	0.10	0	0.90	0
Portsmouth, NH	262	0	0.16	0.08	0.72	0.01	0.03
Rye, NH	137	0	0.50	0	0.49	0	0.01
Scituate, MA	17	0	0	0.06	0	0.94	0
Seabrook, NH	109	0	0.50	0	0.49	0	0.01
Swampscott, MA	9	0	0	1.0	0	0	0

* Four hauls were made in the Mid-Coast area by non-experimental vessels despite the closure restrictions.

Table 4

Proportion of traditional fishing grounds closed to fishermen from different homeports during the Mid-Coast closure in the Gulf of Maine, November 1994, and if the Z-band had been closed during the same period.

Homeport	Mid-Coast closed	Mid-Coast and Z-band closed
Gloucester, MA	0.25	0.56
Boothbay Harbor, ME	0.23	0.32
Portsmouth, NH	0.64	1.00
Rye, NH	0.35	0.61
Hampton, NH	0.68	0.97
Beverly, MA	0.23	0.51

was twice that in November. Thus, to be effective, the closure should have been in place for a much longer period, perhaps from September to November. The decision to close the Mid-Coast area in November was based on a spatial analysis of porpoise bycatches in 1991 and 1992, which indicated that the bycatch rate peaked in the Mid-Coast area in November (New England Fishery Management Council (NEFMC), 1994). Subsequent analyses have demonstrated that significant inter-annual variation exists in the timing and distribution of porpoise bycatches in the Gulf of Maine (Bisack, 1997). For example, in 1994 the estimated total bycatch of porpoises in the southern Gulf of Maine was 1,637 animals, compared to 799 in 1995 (Bisack, 1997). This variation arises from a complex and poorly understood set of interactions among gillnet fishermen, groundfish and harbour porpoises. The timing and extent of seasonal movements made by harbour porpoises is extremely variable from year to year (Read and Westgate, 1997). In addition, the New England multispecies sink gillnet fishery, like many other small-scale fisheries, relies on flexibility to respond to variation in a myriad of market and biological factors. This flexibility includes intra- and inter-annual shifts in the geographic distribution of fishing effort. Such variation makes it difficult, if not impossible, to predict exactly where and when areas should be closed to maximise bycatch reduction.

Displacement of fishing effort and bycatch

During November, fishermen on non-experimental vessels were prevented from fishing in the Mid-Coast area and instead concentrated much of their effort in the unrestricted Z-band and Outside areas, where bycatches also occurred. In addition, there was a higher bycatch rate in the Outside area in November than in previous months. The size of the Mid-Coast closure was a compromise between the desired bycatch reduction goals for harbour porpoises and economic costs imposed on fishermen. During the negotiation process, the New England Fishery Management Council had considered including the Z-band with the Mid-Coast closure because the bycatch of harbour porpoises in this area had been relatively high from 1991 to 1993. Fishermen wanted the Z-band to remain open, however, due to the increased expense and risk involved in travelling to other areas. Ultimately, the Council left the Z-band open to minimise impacts on fishermen (New England Fishery Management Council (NEFMC), 1994). Enlarging the Mid-Coast closure to include the Z-band during November would have reduced bycatch rates of harbour porpoises because bycatch occurred in the Z-band during this time. A larger closure might have reduced this displacement of effort and bycatch since the only recourse left for many of these fishermen would have been to stop fishing.

Fishermen on experimental vessels were authorised to set their nets in any area. Not surprisingly, most fishermen who would have been displaced by the closure chose to participate in the experiment. For example, 93% of fishermen from Portsmouth participated. If they had been restricted by the closure and the Z-band had also been closed, they would have lost all of their traditional fishing grounds. Such closure would have thus imposed a severe cost on fishermen from Portsmouth who would have had to move to new ports to fish in unrestricted areas.

The Mid-Coast closure was an unpopular measure among New England sink gillnet fishermen, who preferred other strategies to reduce the bycatch of harbour porpoises in their fishery. For example, a few individuals continued to set nets in the closed area (4 observed hauls), despite having an observer on board. In particular, fishermen from ports such as Portsmouth, who were most affected by the closure, felt that they were shouldering a disproportionate burden of bycatch reduction. Such inequitable impacts may have hindered full compliance by fishermen to the closure restrictions. Fishermen are more likely to cooperate with regulations if they find them fair and effective, and if the regulations are easy to follow and enforceable.

Future design

The behaviour of both the non-experimental and experimental vessels throughout the autumn fishing season offers some insight into how to plan and design time/area closures based on fishermen's behaviour. There were two major groups in the fishing fleet that differed according to their spatial distribution of effort. Fishermen on the experimental vessels chose to participate in the experiment because otherwise they would have been displaced by the closure. Small time/area closures will have disproportionate impacts on the fishermen involved, particularly if these fishermen come from homeports that are far apart. These disproportionate impacts pose a management challenge. A national standard stated in the Magnuson-Stevens Fishery Conservation and Management Act, the primary legislative mandate in the USA to manage sustainable fisheries, states that any conservation and management measure shall be fair and equitable to all fishermen if it becomes necessary to allocate fishing privileges (Magnuson-Stevens Fishery Conservation and Management Act of 1976, 16 U.S.C. 1851 301(a)(4)). It seems unlikely that small time/area closures can be placed in such a manner to meet the requirements of this national standard.

Secondly, the fact that fishermen on experimental vessels could set their nets in any area allowed us to examine where fishermen chose to operate throughout the autumn season. The spatial distribution of fishing effort was significantly different each month, originating close to shore in September and moving farther offshore as the season progressed. Unless short-term shifts such as these are consistent from year to year, it is difficult to predict how fishermen respond to a closure. If time/area closures are to be implemented without concurrent reductions in fishing effort, closure plans must anticipate the effects of displaced effort. Information is needed on how fishermen respond to a closure, the proportion of effort that is redistributed, bycatch rates in the closure area and in adjacent areas where effort would be redistributed. Total bycatch reduction may be grossly over or under-estimated if these issues are not addressed.

Based on the results from this study, we suggest that there are specific conditions under which time/area closures may be effective in reducing the bycatch of marine mammals. Closures may be effective when: (1) the area where bycatch occurs is a small subset of the area where fishing effort occurs; (2) patterns of bycatch are predictable in time and space; (3) displacement of fishing effort does not result in bycatch rates as high or higher than in the closure area; (4) fishermen support and cooperate with the regulations; and (5) an adequate information base exists on which to design closures. The 1994 Mid-Coast closure did not meet these conditions. Bycatches occurred in an area much larger than that covered by the closure; the spatial and temporal distribution of porpoise bycatch in the Gulf of Maine was not predictable; and displacement of fishing effort and bycatch occurred. Fishermen did not support the closure and, although an information base existed prior to the closure, it was not adequate to design an effective, equitable closure system.

Combining mitigation strategies may be more effective than a single measure in reducing bycatch (IWC, 1994). Modifying gear, such as the placement of pingers on fishing nets, is another strategy used to reduce incidental mortalities of cetaceans (Kraus *et al.*, 1997). Currently in the Gulf of Maine, sink gillnet fishermen are required to use pingers in specified areas and months of the year. This system is used in conjunction with a limited number of complete time/area closures during other months, designed to conserve groundfish stocks and reduce the bycatch of marine mammals. The intent of this strategy is to: (1) address the problem of spatial and temporal variation in bycatch rates and; (2) alleviate economic impacts on fishermen by restricting the imposition of more extensive complete closures.

Several caveats should be noted to the above analysis. Firstly, it was assumed that effort of observed vessels was representative of total effort and that the presence of an observer on board did not influence fishermen's behaviour. Similarly, it was assumed that the six vessels examined for displaced fishing effort were representative of vessels that normally fish in the Mid-Coast area. Secondly, spatial analysis on a finer scale may reveal that the percentage of traditional fishing grounds closed to fishermen from different ports was actually higher, because fishing effort was not distributed evenly throughout the areas examined.

Future assessments of time/area closures should include an examination of the economic impacts on fishermen. Due to changes in the methods of fisheries observer data collected in 1994 (Bisack, 1997), it was not possible to examine fisheries catch data in the same geographical areas we analysed. Examining the distribution of bycatch, as well as the cost of a closure to fishermen, may elucidate whether time/area closures can effectively reduce bycatch while maintaining a viable fishery.

Solutions to bycatch problems will vary among regions, fisheries and species (e.g. Alverson *et al.*, 1994). While time/area closures may be appropriate in some instances, as implemented here it was not an effective technique for reducing bycatches of harbour porpoises in the Gulf of Maine sink gillnet fishery during 1994. The geographical and temporal scope was insufficient and the end result was a displacement of effort and bycatch. If time/area closures are to be used in other regions to reduce bycatch of small cetaceans, without having major adverse economic impacts on fishermen, the bycatch must be highly localised and predictable in time and space. If the conditions suggested here for time/area closures to be effective cannot be met, other solutions to the bycatch problem will need to be considered.

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