Entrapment of harbour porpoises (*Phocoena phocoena*) in herring weirs in the Bay of Fundy, Canada

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ABSTRACT

Harbour porpoises (*Phocoena phocoena*) are small coastal cetaceans vulnerable to mortality in fishing operations. Not all interactions are fatal, however, and each year many porpoises swim into and are subsequently released from herring weirs in the Bay of Fundy, Canada through a targeted release programme. This study examines catch composition, body condition, characteristics associated with mortality and factors affecting entrapment of porpoises in weirs between 1992-2001. A total of 886 porpoises were recorded in weirs during this period. A total of 657 animals were involved in attempted releases: 588 were released alive and 69 were incidentally killed during release. The remainder of the animals swam out on their own or their fates were unknown. Estimated annual mortality represents less than 0.01% of the Bay of Fundy/Gulf of Maine population and only 1.03% of its annual potential biological removal level.

The number of porpoises caught in weirs varied from eight in 1996 to 312 in 2001. Of the 390 animals released with a numbered identification tag, 25 were recaptured in weirs and 4 of those porpoises entered a weir a third time. Males comprised 63.5% of entrapments. Weirs and demersal gillnets captured animals from the same population, but the weir bycatch was biased towards younger, smaller animals. Porpoises that became trapped in weirs exhibited measures of body condition similar to those killed in gillnets and by gunshot wounds in the same waters. None were considered emaciated. Mortality in weirs appeared to be random; porpoises that died during release attempts were of the same age and sex composition and body condition as the individuals that survived. The use of a specialised large-mesh seine significantly increased the probability of successful release. Observations of the stomach contents data of porpoises killed in weirs indicate that porpoises feed while trapped in weirs, but perhaps not at the same rate as animals killed in gillnets. Entrapments peaked in August, concurrent with the highest landings of Atlantic herring, the target species of the weir fishery. Based on a logistical regression model, porpoises are 3.3 times more likely to swim into a weir on a night in which high tide falls during darkness. Weir entrapments do not have a significant effect on this population, largely because of on-going efforts to release porpoises from weirs.

KEYWORDS: HARBOUR PORPOISE; INCIDENTAL CATCHES; FISHERIES; NORTH AMERICA; ATLANTIC OCEAN; CONSERVATION; MORTALITY RATE

INTRODUCTION

As the demand for marine resources increases, particularly in coastal areas, conflicts with marine mammals increase in frequency and severity. Coastal species are particularly vulnerable because of their proximity to human activities. Not all interactions pose a significant threat, however, and each type of interaction needs to be assessed to optimise the use of marine resources while minimising anthropogenic impacts on marine mammal populations.

The harbour porpoise (*Phocoena phocoena*) is a small, coastal cetacean that is vulnerable to fishery interactions throughout its range (Gaskin, 1984; IWC, 1994; Donovan and Bjørge, 1995). These interactions are of particular concern for porpoises from the Bay of Fundy and Gulf of Maine population; large numbers have been killed in sink gillnets set for demersal fish species in these areas in the past (Read and Gaskin, 1988; Read, 1994). Mortality in gillnet fisheries averaged 1,163 porpoises per year from 1994-1998 (Waring *et al.*, 2001). A take reduction plan was implemented in the USA in December 1998, after which gillnet mortality decreased to 270 porpoises in 1999 (Waring *et al.*, 2001). In Canada, total bycatch of porpoises in gillnets was 424 and 101 animals in 1993 and 1994, respectively (Trippel *et al.*, 1996). An estimated 36 porpoises were killed in gillnets in the Bay of Fundy per year from 1995-1999 (Waring *et al.*, 2001). Bycatch in Canadian waters has decreased in recent years because of conservation measures designed to protect overfished groundfish stocks (Trippel *et al.*, 1999). The current abundance estimate for the Bay of Fundy/Gulf of Maine population is 89,700 (53,400-150,900) (Palka, 2000) and the potential biological removal (PBR) for this population is 747 animals per year (Waring *et al.*, 2001). High levels of incidental mortality led the Committee on the Status of Endangered Wildlife in Canada to list porpoises in eastern Canada as threatened (Gaskin, 1992) but in May 2003 this was changed to *Special Concern* (see web at http://www.sararegistry.gc.ca/virtual_sara/files/cosewic/sr%5Fharbour%5Fporpoise%5Fe%2Epdf). This stock is considered strategic by the National Marine Fisheries Service in the United States because prior to 1999, PBR had been exceeded every year (Waring *et al.*, 2001).

Harbour porpoises in the Bay of Fundy are also caught incidentally in herring weirs. Weirs are fixed structures built in shallow water to trap Atlantic herring (*Clupea harengus*). In Canada, the herring weir fishery is restricted to the New Brunswick and Nova Scotian coasts in the Bay of Fundy (Read, 1994) and bycatches in this fishery likely impact only the Bay of Fundy/Gulf of Maine population. Unlike gillnet entanglements, which are almost always fatal, porpoises that enter weirs can be released alive. However, the number of entrapments and subsequent mortality rate have not been well documented. The only published accounts of weir entrapments are found in Smith *et al.* (1983) and briefly in Read (1994). Preliminary data on entrapments up to 1994 were presented to the International Whaling Commission

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(IWC) in 1995 (Neimanis *et al.*, 1995). Smith *et al.* (1983) estimated from a questionnaire survey that approximately 70 porpoises are trapped in weirs in the lower Bay of Fundy each year and 39% of these animals die. These authors concluded that porpoises did not feed while in weirs. Read (1994) reported that the number of entrapments per year had increased and noted that more than 100 animals were released alive in 1993. A thorough and updated account of porpoise entrapments in herring weirs is needed to evaluate the impact of the weir fishery on this population of porpoises.

In 1991, researchers at the Grand Manan Whale and Seabird Research Station (GMWSRS) began to assist local weir fishers with the removal of porpoises from their weirs. This cooperative effort, the Harbour Porpoise Release Program (HPRP), was established to minimise porpoise mortality and provide researchers with access to live, free-ranging animals for further study.

This paper provides a comprehensive account of harbour porpoise entrapments in the lower Bay of Fundy since the last detailed report in 1983 (Smith *et al.*, 1983). The aim is to document which segment of the population becomes trapped, its subsequent fate and to determine which factors contribute to entrapment and outcome. This includes a report of total number of entrapments, catch composition, body condition and mortality rates of trapped porpoises. To investigate factors that may contribute to mortality in weirs, basic life history data and body condition of porpoises that survived are compared with those that died. These parameters also are compared for porpoises trapped in weirs with porpoises that died in gillnets in the Bay of Fundy. An analysis of stomach contents collected from animals that died in weirs is provided to re-examine the hypothesis that porpoises are not feeding while trapped (Smith *et al.*, 1983). To better understand factors that may facilitate porpoise entrapment, herring landing data from weirs are presented in relation to the number of porpoises caught; the effects of tidal cycle, moon phase and season on entrapment are also examined. Finally, the impact of weir mortality on the Bay of Fundy/Gulf of Maine population is evaluated.

MATERIALS AND METHODS

Herring weirs

Herring weirs are fixed impoundments built near shore to catch herring (Fig.1). These kidney-shaped structures are comprised of a number of wooden stakes driven into the sea floor from which a 1cm mesh nylon twine is hung. Weirs enclose an average surface area of 1,500m^2 and range from 3-20m in depth at low tide. The opening or mouth of the weir (i.e. the inner bend of the kidney structure) faces towards shore and a twine fence runs from the mouth to shore. When herring follow the shoreline at night, they encounter the fence and are directed into the weir. Once inside, they swim along the perimeter of the weir in a characteristic figure-eight pattern, which leads them away from the weir mouth.

It is believed that porpoises feeding on schools of herring follow the fish into the weir at night. Between one and 14 porpoises have been recorded to have entered a single weir on a given night around Grand Manan. Some leave the weir independently, but most remain trapped in the weir until they are removed. It is unclear why most porpoises remain in the weir, but individuals may be reluctant to swim through the relatively narrow weir entrance, which is located in the shallowest part of the weir. This behaviour is in stark contrast to that of harbour seals (*Phoca vitulina*) which enter and leave weirs at will.

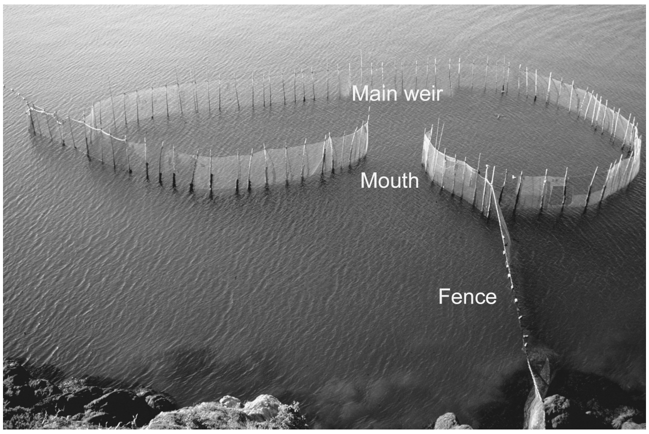

Fig. 1. Overhead view of a herring weir. The fence runs from the shoreline to the mouth and directs herring that are swimming along the shoreline into the main weir.

Removing porpoises from herring weirs

Porpoises are removed from weirs using a seine net and with the direct assistance of the weir operator and seine crew. They can be removed with the herring using a fine mesh purse seine (mesh size 0.75-1.25cm) or released separately with a specialised marine mammal seine. This second net is made from buoyant polypropylene and has a much larger mesh size (7.5cm) which allows herring to pass through while capturing larger animals, such as porpoises, tuna and sharks. Porpoises are typically pursed in the seine, transferred to a boat and transported outside of the weir for release. Occasionally, the seine is deployed as a barrier to sweep animals out of the weir. Porpoises swept out in this manner are released without being handled and no additional data are collected. If an animal dies during seining, an attempt is made to recover the carcass and a necropsy is performed following standard protocols (American Society of Mammalogists, 1961; McLellan *et al.*, 2002).

Processing and releasing porpoises

Basic data are collected from each animal whenever possible, including sex, total length and maximum girth. Tooth eruption is verified to identify calves and mammary glands of females are checked for lactation. A coloured, numbered roto-tag (*Dalton Jumbo Roto-tags*, Dalton E.I.D. Systems, Oxfordshire, UK) is applied to the trailing edge of the dorsal fin for future identification. Finally, porpoises are weighed and then released outside the weir. Whenever feasible, additional samples and data are collected from a subset of animals. Blood samples are obtained from a fluke vessel for a complete blood count, biochemistry profile and other analyses (Koopman *et al.*, 1995; 1999). Since 1998, the heart rate of selected animals is continuously recorded throughout processing and handling procedures are videotaped to record additional information. Some porpoises are fitted with VHF transmitters, combination VHF transmitters/time-depth recorders and/or satellite transmitters (Westgate *et al.*, 1995; Read and Westgate, 1997; Westgate and Read, 1998).

Data analyses

Records of entrapment and the subsequent fate of individual porpoises were collected for 961 animals that entered herring weirs in the Bay of Fundy from 1984-2001 (Table 1). It was not possible to collect a complete suite of data and samples from every animal, as some individuals were released unprocessed, some were observed in weirs but subsequently disappeared and some carcasses were not retrieved from the seine. Thus, sample sizes vary for each analysis performed. Entrapments were recorded between June and October. Prior to 1991, releases were opportunistic and effort was highly variable. By 1992, the release programme had become well-established and began to release porpoises in considerable numbers (Table 1). From 1995, local weirs were monitored daily and date of porpoise entrapments were recorded. Weather permitting, every weir within a 10km radius of North Head, Grand Manan was examined by boat each morning. Not all weirs could be examined every day and the number of local weirs built varied between years. The total number of weirs checked regularly from 1995-2001 varied from 18 to 22. All data analyses were restricted to 1992-2001, when effort levels were comparable. Only eight entrapments were recorded in 1996, so this year was excluded from statistical comparisons among years. All statistical analyses except for logistic regression were carried out using SPSS 10.0 (SPSS Inc, Chicago, IL). Logistic regression was performed using SAS/STAT 6.0 (SAS Institute Inc, Cary, NC). Tests were performed assuming an alpha level of 0.05, unless otherwise stated.

Table 1

Summary of recorded entrapments and subsequent fate of harbour porpoises in herring weirs in the lower Bay of Fundy from 1984-2001.

Year	Released alive*	Died during release*	Swam out	Shot	Fate unknown	Total no. recorded in weirs
1984	4 (4)	0	0	0	0	4
1985	5 (5)	0	0	3	0	8
1986	0	0	0	1	0	1
1987	0	0	0	1	0	1
1988	0	1 (0)	0	4	0	5
1989	1 (0)	1 (0)	0	0	0	2
1990	24 (7)	7 (0)	0	1	9	41
1991	11 (7)	0	1	0	1	13
1992	39 (37)	11 (11)	11	0	11	72
1993	115 (113)	21 (21)	0	8	9	153
1994	41 (40)	11 (11)	5	0	20	77
1995	54 (53)	4 (4)	17	0	7	82
1996	2 (2)	3 (1)	2	0	1	8
1997	23 (20)	2 (2)	3	0	7	35
1998	12 (12)	2 (2)	19	0	1	34
1999	48 (47)	3 (3)	33	0	9	93
2000	12 (12)	0 (0)	3	0	5	20
2001	242 (237)	12 (12)	56	0	2	312
Total	633 (596)	78 (67)	150	18	82	961

*( )=GMWSRS present.

Catch composition

To examine catch composition of porpoises caught in weirs, both animals that were successfully released ($n = 521$) and those that died ($n = 68$) were included. This excluded animals that were released unprocessed, swam out, were swept out or disappeared before seining. Sex ratios were calculated by year and compared using Chi-Square tests ($n = 544$). Since porpoises exhibit sexual dimorphism (Read and Tolley, 1997), body length data were analysed separately for males ($n = 310$) and females ($n = 173$). Mean total lengths were determined by year and compared using ANOVA. As yearly variances were unequal (Levene's test, $p < 0.02$ for both males and females), *post-hoc* comparisons of ANOVA results were made using Tamhane's T2 (Tabachnick and Fidell, 1996). Total lengths were grouped by 5cm increments and length distributions were compared between years for each sex using Kruskal-Wallis tests (Zar, 1974). Age estimates for carcasses collected from weirs were obtained from counts of dentinal growth layers in stained decalcified thin sections of teeth (Bjørge *et al.*, 1995). Mean age and age distribution were compared between 1992 and 1993, when sample sizes were large enough ($n = 9$ and $n = 16$, respectively); ages were not yet available for the 2001 season. An independent samples T-test was used for comparison of mean age and a Kruskal-Wallis test was used for age distribution.

To determine if weir catches were similar in composition to the population of porpoises caught in gillnets, sex ratios, mean lengths, length distributions, mean ages and age distributions of animals caught in weirs were compared to animals killed in gillnets in the lower Bay of Fundy during the same period. All necropsies of gillnet bycatches were performed by the GMWSRS following standard protocols (American Society of Mammalogists, 1961; McLellan *et al.*, 2002). The same statistical analyses were used as described above for weir catch composition. Analyses were restricted to 1992 and 1993, when adequate sample sizes were available from both the weir ($n = 44$ and $n = 108$ for 1992 and 1993, respectively) and gillnet ($n = 19$ and $n = 36$ for 1992 and 1993, respectively) samples. This eliminated the potential influence of interannual variation. Age estimates were only available for dead animals, so sample sizes for age comparisons were 9 and 16 for the weir sample in 1992 and 1993, respectively. Catch composition of porpoises caught in gillnets in 1992 was also compared to that of gillnet mortalities in 1993.

Recaptures

Of the 886 porpoises recorded in weirs from 1992-2001, 390 were fitted with a numbered tag for future identification. Of these, 25 animals were recaptured in a weir at least once. Sex ratio, mean length and length distribution of recaptured animals were determined ($n = 25$). Mean length and length distribution were determined separately for males ($n = 17$) and females ($n = 8$) as above. These results were then compared with those for porpoises that only swam into a weir once ($n = 510$). A Chi-square test, an independent T-test and Kruskal-Wallis analyses were used for sex ratio, mean length and length distribution comparisons, respectively.

Mortality rates

Mortality rates of trapped porpoises were determined for each year and compared among years. Rates were calculated in the following two ways: the number of animals that died in weirs was divided by the total number recorded in weirs, excluding those with an unknown fate (total $n = 814$); the number of animals that died during seining was divided by the total number of porpoises for which a seine was attempted (total $n = 581$). Seines were only included in which personnel from the GMWSRS were present; porpoises that were swept out of weirs were excluded. To examine efficacy of the mammal seine, mortality rate of porpoises seined out with this net ($n = 240$) was compared with that calculated for animals released with the herring seine ($n = 239$) using a Chi-square test. Again, animals swept out were excluded. A further aim was to determine if the number of porpoises present in the seine had any effect on mortality. To avoid variation from type of net used, this analysis was conducted only for porpoises captured in herring seines. Mortality rate during seines for solitary animals ($n = 63$) was compared with multiple animals ($n = 176$) using a Chi-Square test. Animals that were swept out were excluded. In addition, mean number of animals per seine that survived ($n = 195$) was compared with those that died ($n = 44$) using an independent samples T-test.

Body condition of entrapped porpoises

To determine the body condition of porpoises that swim into weirs, total mass (used here as a measure of body condition) was compared among three groups of porpoises: all trapped animals (live releases and mortalities, $n = 99$); porpoises from the Bay of Fundy that died as the result of other human interactions (HI) such as gillnet entanglement or were shot ($n = 15$); and porpoises deemed to be in poor condition ($n = 19$). This latter group represents individuals found stranded on beaches along the mid-Atlantic coast of the United States. They exhibited no evidence of human interaction, presented with a visible depression behind the blowhole and sunken epaxial musculature (Kastelein and van Battum, 1990; Koopman, 2001), and changes in muscle fibre profiles indicate they have starved to death (Stegall *et al.*, 1999). Starvation is associated with a significant decrease in blubber thickness in porpoises from the mid-Atlantic (Koopman *et al.*, 2002). Preliminary comparison of a set of robust animals in good body condition killed in fishing interactions in the mid-Atlantic with robust specimens from the Bay of Fundy indicated that blubber thickness was not significantly different between porpoises < 130cm in length from the two geographical regions (H. Koopman, unpublished data). Thus, emaciated animals from the mid-Atlantic were assumed to be a reasonable comparative group for the weir and gillnet analyses reported here. Total mass increases with body length, and thus values must be corrected for body size prior to comparison. In this dataset, the relationship between body length and body mass was $\text{mass} = (\text{length})^{2.376}$ ($p < 0.001$, adjusted $R^2 = 0.89$). Body mass was compared among the three groups by first linearly regressing length$^{2.376}$ against mass, and then submitting residual values to ANOVA. Levene's test was used to determine equality of variances between groups tested (Tabachnick and Fidell, 1996). *Post-hoc* comparisons of all ANOVA tests then were made using either Sidak's test (group variances were the same) or Tamhane's T2 test (group variances differed significantly). Most of the stranded porpoises were juveniles and so only porpoises with total body length < 130cm were included in this comparison.

Factors associated with weir mortality

To examine which factors might be correlated with mortality during release, sex ratios, mean lengths and length distributions of porpoises that survived the seine ($n = 483$) were compared with those that did not ($n = 61$). Animals that were swept out were excluded. Comparisons were made using Chi-Square, independent samples T-test and Kruskal-Wallis tests, respectively.

To determine whether poor body condition was associated with an increased chance of mortality, the size-corrected body mass of porpoises that were successfully released ($n = 140$) was compared with those that died during release attempts ($n = 63$). These two groups of porpoises represented the same size classes: mean standard lengths of live (128.4 ± SE 0.75cm) and dead (128.9 ± SE 2.03cm) weir porpoises were not significantly different when compared with an independent samples T-test ($p = 0.816$), thus all animals for which data were available were included. Body mass was compared between live and dead weir porpoises using ANCOVA with length$^{2.376}$ as the covariate.

Finally, to determine whether porpoises that died in the weir fishery were in the same condition as individuals killed in the local groundfish gillnet fishery, the body condition of porpoises that died during seining was compared with that of porpoises that died in gillnets in the Bay of Fundy. All porpoises in this analysis were dead, so it was possible to include dorsal blubber thickness measured just anterior to the dorsal fin ($n = 59$ and $n = 56$ for weir and gillnet animals, respectively), in addition to girth just anterior to the dorsal fin ($n = 60$ and $n = 56$ for weir and gillnet animals, respectively), and body mass ($n = 63$ and $n = 54$ for weir and gillnet animals, respectively). As above, mass was compared between gillnet and weir mortalities using ANCOVA with length$^{2.376}$ as the covariate. Blubber thickness is negatively correlated with body size in harbour porpoises (Koopman, 1998) and so both girth and dorsal blubber thickness were compared between gillnet and weir mortalities using ANCOVA with length as the covariate. ANCOVA revealed that blubber thickness showed no relationship with length in this sample ($p = 0.490$), thus the comparison was repeated using ANOVA.

Stomach contents

Stomachs were examined from porpoises killed in herring weirs ($n = 42$) and gillnets ($n = 46$) from 1992-1999 in the Bay of Fundy to determine if porpoises fed while in weirs. Porpoises that were shot were excluded from the analysis because it was not possible to determine if they were shot in weirs or in open water. Stomachs were examined following the methods described in Recchia and Read (1989).

Determination of feeding activity was examined in four different ways. The mass of forestomach contents of animals collected from weirs was compared with those from porpoises killed in gillnets. Content mass was determined by weighing the forestomach full and empty and subtracting the difference. There was a significant correlation ($p < 0.0001$ and $R^2 = 0.68$) between body mass and empty stomach mass. Thus, forestomach content mass was compared between the weir and gillnet samples using ANCOVA with body mass as the covariate. A comparison was also made between the proportion of empty stomachs (operationally defined as a forestomach content mass less than 10% of the empty forestomach mass) of porpoises caught in weirs and gillnets with a Chi-Square test. The proportion of stomachs containing fresh prey was compared between the weir and gillnet sample with a Chi-Square test. Fresh items were defined as ingested prey items in the stomach or oesophagus that still had $> 90\%$ of the flesh intact. The number and composition of otoliths and other prey remnants were determined for each sample. This allowed a prey species count to be assigned to each stomach. Each species of prey found in a stomach was counted as one unit. Species counts were compared between the weir and gillnet samples using an independent samples T-test.

Factors facilitating entrapment

Porpoises probably follow herring, their primary prey, into weirs, so porpoise entrapments should be correlated with the abundance of herring in weirs. Data on herring abundance in weirs were not available, therefore landings were used as a proxy (M.J. Power, Department of Fisheries and Oceans, St. Andrews, NB, Canada, pers. comm.) Porpoise entrapments from 1992 to 2001 are plotted by month with herring landing data from Grand Manan weirs during this same time period (Fig. 4).

Local weir fishermen claim that porpoises are most likely to swim into weirs on nights when high tide falls during darkness and just after a full moon. To determine whether timing of high tide or phase of the moon affected the probability of a porpoise swimming into a weir, each night of the monitoring period was classified according to these two variables. This analysis was restricted to 1995, 1999 and 2001, when there was an adequate number of recorded entrapments ($n = 82$, $n = 93$ and $n = 312$, respectively). Tables published by the Canadian Hydrographic Service (1995; 1999; 2001) provided daily times of high tides in waters around Grand Manan Island. Some light is present before sunrise and after sunset, so darkness was defined as the time span between civil twilights (sun's zenith distance is 96°). Civil twilight times were determined for each night using the Astronomical Almanac (Anon., 1995; 1999; 2001). Greenwich Mean Time (Longitude = 0°) was adjusted to the local time of North Head, Grand Manan Island (66°47'W) by adding four hours and 27 minutes. An hour was then subtracted to account for Daylight Saving Time observed in New Brunswick during the summer months. Nights were categorised according to whether high tide fell between twilights ($n = 158$) or not ($n = 52$).

To examine moon phase effects, nights were divided into four groups corresponding to the quarters of the moon. Dates of each quarter were determined from The Astronomical Almanac (Anon., 1995; 1999; 2001). The moon phase categories were labelled from 1 to 4 in cyclical order with 1 corresponding to the first quarter, i.e. from the new moon to the waxing half moon, and 4 corresponding to the last quarter, i.e. from the waning half moon to the new moon.

The moon affects the marine environment in two ways: illumination and tides. Additionally, the pattern of spring and neap tides is dictated by the position of the moon relative to the earth. Around Grand Manan Island, the greatest tidal amplitudes (i.e. spring tides) occur just after the full and new moons (Canadian Hydrographic Service, 1995; 1999; 2001). During these times, entrances to weirs will be the deepest at high tide. In an effort to separate lunar influences on tidal amplitude from brightness, the four moon phases were grouped to test for each effect (Table 2).

Table 2

Groupings of the four quarters of the moon to test for lunar influence on tidal amplitude (spring versus neap tides) and light level for waters around Grand Manan, NB. The first quarter is defined as the period from the new moon to the waxing half moon and the fourth quarter corresponds to the time period from the waning half moon to the new moon.

Lunar effect	1st quarter (1)	2nd quarter (2)	3rd quarter (3)	4th quarter (4)	Groupings of lunar quarters
Tidal amplitude	Large (spring)	Small (neap)	Large (spring)	Small (neap)	1&3 vs 2&4
Brightness	Dark	Bright	Bright	Dark	1&4 vs 2&3

More than one porpoise may swim into a particular weir on a given night so these entrapments cannot be considered as independent events. The animals may have been foraging in a group or the detection of a porpoise feeding may have attracted other animals to the same herring school. However, local regulations require that weirs must be built at least 305 metres apart, so two animals swimming into two different weirs on the same night were treated as independent events. Porpoise entrapments were viewed as binary response data. On a given night, a particular weir will either catch at least one porpoise ($Y = 1$) or it will not ($Y = 0$).

A logistic regression model describes the effects of a set of explanatory variables on a response variable (Agresti, 1984) and it is therefore appropriate for determining which factors affect porpoise entrapment. The logistic regression model can be generalised as:

$$\text{logit}\,(p) = \log\,[\,p\,/\,(1-p)\,] = \alpha + \beta_1 x_1 + \ldots + \beta_k x_k$$

where logit is the log odds transformation (i.e. the log of the probability that a given event will occur divided by the probability that it will not) and p is the probability that $Y = 1$ for the values of explanatory variables $X = (x_1, \ldots x_k)$ (Agresti, 1984). The explanatory variables included in this model were high tide at night, lunar influences on tidal amplitude and nocturnal light level as described in Table 2, Julian date, year and interactions between high tide at night, lunar effects, Julian date and year. As porpoise entrapments in gillnets and weirs peaked in mid-August (Read and Gaskin, 1988; Neimanis *et al.*, 1995; Fig. 4), date of entrapment was thought to be best represented by a quadratic (i.e. parabolic) function. Therefore, Julian date squared and higher order date variables were also considered in the model. Logistic regression models were fitted using the method of maximum likelihood. The null hypothesis (the probabilities of an entrapment occurring versus not occurring were equal when considering the explanatory variables) was tested against the alternative hypothesis (the probabilities were different). The test statistic used was minus twice the difference of the log likelihoods and it represented the joint significance of all explanatory variables ($\alpha = 0.05$). If the −2 Log Likelihood was significant (i.e. the probabilities differed), an analysis of maximum-likelihood estimates was used to assess the significance. Variables that did not contribute significantly to the occurrence of an entrapment ($\alpha > 0.10$) were then excluded from the model. Logistic regression analysis, in the context of a general linear model, was repeated until the most parsimonious model was determined.

Logistic regression analysis revealed that year was a significant variable because of the inclusion of 2001. This was a highly anomalous year (see Table 1). From 17 July to 9 September 2001, at least one porpoise swam into a weir every night. Thus, other factors influencing entrapment could not be evaluated during this year. We therefore excluded 2001 from the logistic regression model in order to determine equations that more accurately modelled porpoise entrapment during average years.

RESULTS

Catch composition

The sex ratio of weir entrapments was biased towards males in 1993 ($p = 0.005$), 1995 ($p = 0.005$), 2001 ($p < 0.001$) and all five porpoises released in 1996 were males (Table 3). The sex ratio did not differ significantly from year to year ($p = 0.212$) and there were no significant differences in sex ratio of the weir and gillnet samples in 1992 and 1993 ($p = 0.518$ and $p = 0.842$, respectively).

Mean length of female porpoises trapped in weirs did not differ significantly among years ($p = 0.513$), nor did it differ significantly from the gillnet sample in 1992 ($p = 0.086$; Table 4). However, mean length of female porpoises caught in weirs was significantly less than that of the gillnet sample in 1993 ($p = 0.002$). Mean length of male porpoises caught in weirs in 1995 was significantly different from males caught in 1992 ($p = 0.001$), 1993 ($p = 0.002$) and 2001 ($p = 0.004$). The mean length of males caught in weirs in 1992 and 1993 was significantly less than that of the gillnet sample from those years ($p = 0.002$ and $p < 0.001$, respectively).

Table 3

Sex ratios of harbour porpoises caught in herring weirs and gillnets from 1992-2001 in the lower Bay of Fundy. Ratios that differed significantly from 1:1 are indicated by *. There was no significant difference in sex ratio of the weir sample between years and sex ratios of the weir and gillnet samples did not differ significantly in 1992 and 1993. Statistical tests were performed at an alpha level of 0.05.

Year	Weir sample Males : Females (n)	Gillnet sample Males : Females (n)
1992	1.59 : 1 (44)	1.11 : 1 (19)
1993	1.74 : 1 (107)*	1.57 : 1 (35)
1994	0.87 : 1 (43)	1 : 1 (2)
1995	2.7 : 1 (37)*	0 : 1 (2)*
1996	1 : 0 (5)*	-
1997	1.89 : 1 (20)	2 : 1 (6)
1998	1.33 : 1 (14)	-
1999	1.77 : 1 (36)	-
2000	0.50 : 1 (12)	1 : 0 (1)
2001	1.94 : 1 (226)*	1 : 1 (6)
Total	1.72 : 1 (544)	1.22 : 1 (71)

Length distributions of female porpoises captured in weirs did not differ significantly among years ($p = 0.340$). Length distributions of male porpoises in weirs did differ significantly between years ($p < 0.001$), but when 1995 was excluded from the analysis, the distributions were no longer significantly different ($p = 0.426$). Length distributions differed significantly between animals caught in weirs versus gillnets (Fig. 2) in 1992 and 1993 for both females ($p = 0.033$ and $p = 0.001$, respectively) and males ($p = 0.007$ and $p < 0.001$, respectively).

Mean age of animals that died in weirs in 1992 (1.44 ± 0.53 years) was not significantly different ($p = 0.059$) from that in 1993 (2.94 ± 2.86 years). Age distributions also did not differ significantly between years ($p = 0.471$). Mean age of porpoises that died in gillnets was 3.12 ± 1.83 and 3.30 ± 2.19 years for 1992 and 1993, respectively. Mean age and age distribution of porpoises that died in weirs differed significantly from animals that died in gillnets in 1992 ($p = 0.014$ and $p = 0.002$, respectively). However, in 1993, there were no significant differences in mean age and age distribution between the two samples ($p = 0.623$ and $p = 0.209$, respectively). Pooled age distributions from the weir and gillnet samples are presented in Fig. 3.

Recaptures

Of the 390 porpoises that were fitted with a numbered identification tag, 25 of these animals swam into a weir a second time and four animals swam into a weir a third time. Twenty porpoises were recaptured during the same summer and four animals swam back into the same weir. Mean and median number of days between captures were 220.1 and 9, respectively (range = 0 to 3,274 days). Two animals released together from one weir swam into a second weir on the same day. One mature male first tagged in 1992 was later recaptured in 2001. The sex ratio of recaptures was 2.25:1 males to females, although this did not differ significantly from 1:1 ($p = 0.072$) nor was it significantly different from the sex ratio of weir animals caught only once (1.62:1 males to females) ($p = 0.530$). Mean length for recaptured males (123.8 ± 14.5cm) did not differ significantly ($p = 0.134$) from males trapped in weirs only once (128.6 ± 12.7cm). Mean length of females recaptured in weirs (123.1 ± 18.2cm) was not significantly different ($p = 0.283$) from females caught once (129.6 ± 16.7cm). Length distributions did not differ significantly between single captures and recaptures

Table 4

Mean lengths of harbour porpoises caught in herring weirs and gillnets from 1992-2001 in the lower Bay of Fundy. Males and females were analysed separately. For the weir sample, mean lengths for years that share the same upper case letters were not significantly different from each other. There were no significant differences between years in the gillnet sample. Lower case letters denote comparisons between the weir and gillnet samples for a given year. Different lower-case letters indicate significantly different mean lengths between animals caught in weirs versus gillnets. Statistical tests were performed at an alpha level of 0.05.

	Weir sample Mean length (cm) ± st. dev. (n)		Gill net sample Mean length (cm) ± st. dev. (n)	
Year	Males	Females	Males	Females
1992	125.4 ± 9.2 (26) Aa	127.9 ± 15.3 (17) Aa	138.2 ± 10.2 (8) b	137.9 ± 9.5 (9) a
1993	126.8 ± 10.6 (60) Aa	129.1 ± 9.8 (29) Aa	138.1 ± 10.0 (22) b	141.2 ± 14.4 (15) b
1994	127.0 ± 16.0 (20) AB	124.3 ± 22.9 (20) A	142.5 (1) -	144.0 (1) -
1995	140.3 ± 14.0 (26) B	129.0 ± 24.9 (9) A	-	130.0 ± 46.7 (2) -
1996	113.9 ± 20.4 (5) -	-	-	-
1997	129.5 ± 13.3 (10) AB	119.9 ± 13.3 (7) A	131.6 ± 15.6 (4) -	140.4 ± 27.6 (2) -
1998	121.8 ± 16.3 (8) AB	125.7 ± 28.2 (6) A	-	-
1999	131.4 ± 14.5 (24) AB	136.9 ± 20.5 (10) A	-	-
2000	125.3 ± 7.5 (4) AB	130.5 ± 12.9 (8) A	123.0 (1) -	-
2001	127.4 ± 11.7 (133) A	131.2 ± 15.1 (68) A	143.5 ± 13.4 (3) -	131.3 ± 10.0 (3) -

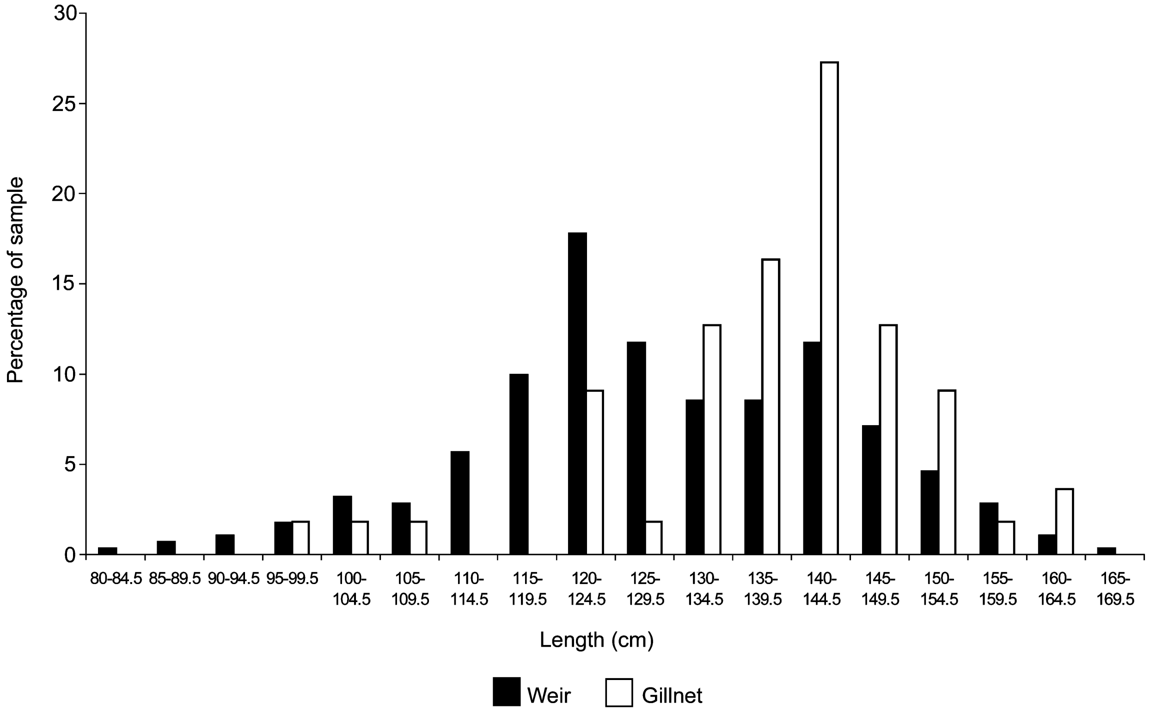

Fig. 2. Standard length distributions (in cm) of harbour porpoises trapped in herring weirs or killed incidentally in groundfish gillnets in the Bay of Fundy from 1992-2001. Animals in each length class are represented as a percentage of the total number of animals in each sample.

($p = 0.159$ and $p = 0.514$ for male and female comparisons, respectively). Both immature and mature animals were represented in the recaptured sample.

Mortality rates

Overall mortality for porpoises recorded in weirs was 9.5% and mortality rate of porpoises for which a seine was attempted was 12.0% (Table 5). Mortality rate for animals seined out using the mammal seine (2.5%) was significantly lower ($p < 0.001$) than that for animals removed with the herring seine (18.4%). Mortality rate of solitary porpoises seined out with the herring seine (19.0%) did not differ significantly ($p = 0.879$) from that of seines involving more than one porpoise (18.2%). Mean number of porpoises present in successful seines (2.13 ± 2.37) did not differ significantly ($p = 0.113$) from the mean number of animals in herring seines in which at least one animal died (2.45 ± 3.27).

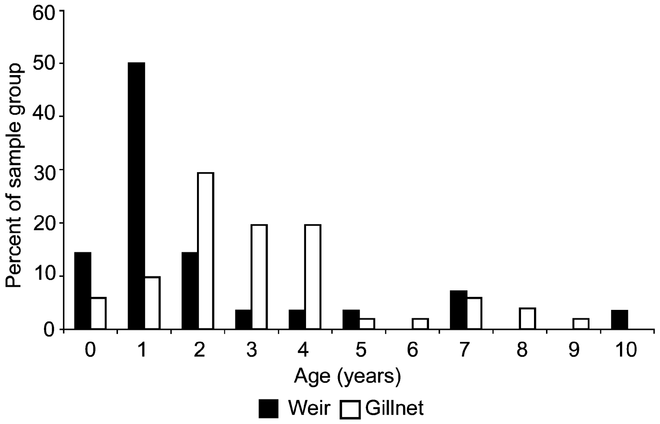

Fig. 3. Age distribution of harbour porpoises killed in herring weirs and gillnets in the lower Bay of Fundy from 1992-1999. Animals in each age class are represented as a percentage of the total number of animals in each sample.

Table 5

Annual mortality rates for harbour porpoises trapped in herring weirs in the lower Bay of Fundy from 1992-2001.

Year	Percentage mortality in herring weirs[1]	Percentage mortality during seining[2]
1992	18.0% (11/61)	22.9% (11/48)
1993	20.1% (29/144)	16.5% (22/133)
1994	19.3% (11/57)	27.7% (13/47)
1995	5.3% (4/75)	10.5% (4/38)
1996	42.9% (3/7)	33.3% (1/3)
1997	7.1% (2/28)	9.1% (2/22)
1998	6.1% (2/33)	14.3% (2/14)
1999	3.6% (3/84)	8.3% (3/36)
2000	0% (0/12)	0% (0/12)
2001	3.9% (12/310)	5.3% (12/228)
Total	9.5% (77/814)	12.0% (70/581)

[1] All porpoises that died in herring weirs divided by the total recorded in weirs excluding those with an unknown fate. [2] Porpoises that died during seining divided by the total number for which a seine was attempted. Only seines where GMWSRS personnel were present were included.

Body condition

Porpoises that became trapped in weirs were in the same body condition as other porpoises in the Bay of Fundy; all juvenile (< 130cm) porpoises were in significantly ($p < 0.001$) better condition than stranded, emaciated animals. Body size was a significant factor in the analysis ($p < 0.001$). Once corrected for body size, juvenile weir and HI porpoises had a similar ($p = 0.85$) body mass (adjusted means: weir 31.99 ± SE 0.32kg; HI 31.52 ± SE 0.82kg) that were both significantly ($p < 0.001$) heavier than those of the juvenile stranded sample (adjusted mean 21.29 ± SE 0.74kg).

Porpoise characteristics associated with mortality

Sex ratio did not differ significantly ($p = 0.872$) between porpoises that survived the seine (1.73:1 males: females) and animals that died during seining (1.65:1 males: females). Mean length of female porpoises that survived the seine

(129.0 ± 16.2cm) did not differ significantly ($p = 0.636$) from mean length of females that died (130.8 ± 20.8cm). Mean length of males that survived seining (128.3 ± 12.8cm) did not differ significantly ($p = 0.645$) from males that died (129.3 ± 11.8cm). Length distributions did not differ significantly between the two samples either ($p = 0.764$ and $p = 0.697$ for females and males, respectively).

Body condition did not differ significantly between animals that survived the seine versus those that died. Once the significant effect ($p < 0.001$) of body size was removed, body mass of released porpoises (adjusted mean 41.29 ± SE 0.35kg) and weir mortalities (adjusted mean 41.24 ± SE 0.52kg) were not significantly different ($p = 0.945$).

There were no significant differences ($p = 0.585$) in girth between porpoises killed in the weir fishery (adjusted mean 86.48 ± SE 0.54cm) and those from groundfish gillnets (adjusted mean 86.92 ± SE 0.56cm) once the effect of body size ($p < 0.001$) was removed. Mean blubber thickness of weir (mean 21.1 ± SE 0.8mm) and gillnet mortalities (mean 19.9 ± SE 0.8mm) was not significantly different ($p = 0.241$). However, once body size was accounted for ($p < 0.001$), porpoises that died in the weir fishery (adjusted mean 43.0 ± SE 0.4kg) possessed slightly higher ($p = 0.004$) mean body masses than animals from gillnets (adjusted mean 41.2 ± SE 0.4kg).

Stomach contents

Using body mass as a covariate, forestomach content mass of animals that died in weirs was significantly less than that of animals killed in gillnets ($p < 0.001$). However, there was no significant difference between the proportion of animals with empty stomachs that died in weirs (21.4%) versus those that died in gillnets (14.0%) ($p = 0.349$). Only one stomach of the weir-caught sample (2.4%) contained fresh prey compared to 18 stomachs (36%) from the gillnet sample ($p < 0.001$). Herring comprised 97.9% of the prey in the weir sample, but only 78.8% of the prey in the gillnet sample (Table 6). Excluding empty stomachs, the prey-species count for weir-caught animals (1.21) did not differ significantly ($p = 0.078$) from that of animals that died in gillnets (1.43).

Table 6

Proportion of prey items ingested by harbour porpoises killed in herring weirs and gillnets in the western Bay of Fundy from 1992-1999 as indicated by prey otoliths and hard parts.

Prey species	Weir sample	Gillnet sample
Clupea harengus	0.979	0.788
Merluccius bilinearis	0.005	0.122
Gadid sp.	0.009	0.009
Urophysis sp.	0	0.004
Myxine glutinosa	0	0.065
Cephalopod sp.	0.005	0.013
S. scombrus	0.002	0

Factors associated with entrapment

Porpoise entrapments mirrored herring landings, with both showing peaks in August (Fig. 4). The final logistic regression model included the intercept ($p = 0.010$), tide phase at night ($p = 0.006$), moon light ($p = 0$ .050), Julian date ($p = 0.015$), Julian date squared ($p = 0.011$) and moonlight by Julian date ($p = 0.032$). It is represented by the following equation:

$$\text{Logit}\,(p) = -47.799 + 1.1926(\text{tide}) - 6.7703\beta + 0.40955(\text{date}) - 0.000963(\text{date})^2 + 0.03314\beta(\text{date})$$

where tide = 1 if high tide falls during the night or tide = 0 if it does not and date is the numerical day of the year, with 1 January as 1. Solving the equation for β (moonlight) with a given tide and day of the year will give the logit (L) for that day. The anti-logit represents the probability that a porpoise will swim into a weir. Using the following equation: $p = e^L/1+e^L$, one can determine the probability of a porpoise swimming into the weir on that given day.

Year, tidal amplitude and other interactions were not significant ($p > 0.10$) and were therefore excluded from the model. The odds ratio of an entrapment occurring on a night when high tide falls during darkness was 3.3. Odds ratios for moonlight, Julian date, Julian date squared and moonlight*date are 0.001, 60.1, 0.91 and 1.4, respectively.

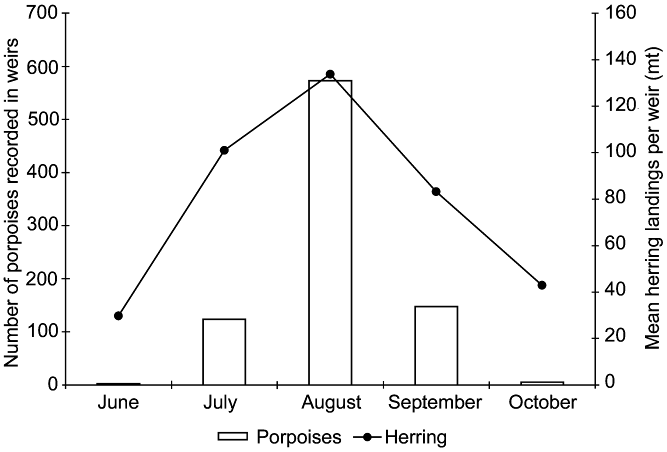

Fig. 4. Monthly distribution of harbour porpoises recorded in herring weirs around Grand Manan versus mean herring landings (mt) per Grand Manan weir from 1992-2001.

DISCUSSION

The weir fishery in the lower Bay of Fundy has an insignificant impact on the Bay of Fundy/Gulf of Maine population of harbour porpoises. With the assistance of the porpoise release programme, weirs kill less than 0.01% of the population each year. Since the inception of the HPRP, weir mortality accounts for 1.03% of PBR each year (0% in 2000 to 3.88% in 1993).

With the exception of 1995, the population of animals that entered herring weirs was similar from year to year. Mean age and age distributions for both sexes did not differ between years, nor did mean length and length distributions for trapped females. If 1995 is excluded, the same was true for male porpoises. However, the weir sample in 1995 was over-represented by large males and these males were significantly longer than males caught in 1992, 1993 and 2001. In general, males are over-represented in the weir sample, comprising 63.2% of the total porpoises examined, although sex ratio was only significantly male-biased in 1993, 1995, 1996 and 2001. The biological significance of the shift in composition of weir entrapments in 1995 is unknown.

Porpoises captured in herring weirs represent a slightly different subset of the general population than animals entangled in gillnets. Sex ratio did not differ significantly between the weir and gillnet samples and the range of lengths and ages were similar between weir (84.5-167cm and 0-10 years) and gillnet (97-163cm and 0-9 years) animals. However, there were significant differences in mean length and age and their respective distributions. With the exception of mean length of female porpoises in 1992, mean length and length distributions differed significantly between the weir and gillnet samples for both sexes. Weir-caught porpoises had a greater proportion of smaller animals than the gillnet sample and mean length was shorter for the weir group. Likewise, weir animals from 1992 had a younger mean age and a greater proportion of younger animals than porpoises caught in gillnets in 1992. There was no significant difference in age parameters between the two groups in 1993. We conclude that weirs and gillnets capture animals from the same general population, but weirs are biased towards younger, smaller animals.

Only a small proportion (6.4%) of porpoises fitted with an identification tag swam into weirs a second time and of those, 16% were recaptured a third time. It is not possible to predict which animals are more likely to swim into a weir again. The catch composition of recaptures was not significantly different from animals that were only trapped in weirs once. However, a recaptured porpoise has a higher probability of swimming into a weir a third time than a released animal has of becoming trapped a second time.

The conclusion that weirs capture animals from the same general population as animals taken in other human interactions is further strengthened when considering body condition data. There were no significant differences in body condition between animals caught in weirs and those killed in gillnets or shot, but both were in significantly better condition than the stranded and emaciated sample. These results demonstrate that the porpoises observed entrapped in weirs exhibit the same body condition as other porpoises in the Bay of Fundy, and that they are also much fatter than porpoises known to be in poor body condition. If porpoises trapped in weirs were debilitated from illness or starvation, they would be expected to be in poor condition. Andersen (1974) concluded that 90% of porpoises caught in Danish trap nets were sick, many with lung parasites and pneumonia. Chronic pneumonia is typically accompanied by a loss in body condition (e.g. Ettinger and Feldman, 2000), which was not evident here. Blood analyses (haemogram and chemistry) did not reveal overt indications of illness (Koopman *et al.*, 1995; 1999), although cortisol levels were higher than in other cetaceans. Increased levels of cortisol can accompany fever or illness (e.g. Lorenz and Cornelius, 1993), but based on the absence of other haematological or gross evidence of disease, we believe these increases are caused by the stress of entrapment and release. Andersen (1974) also found that many porpoises in Danish trap nets died within one hour to two days after capture. Our recapture and electronic tagging data do not support a similar situation for porpoises caught in herring weirs. Mean satellite tag duration to date has been approximately 70 days and the longest track duration was 212 days (Westgate and Read, 1998). The longest period between recaptures was nine years. We therefore conclude that Andersen's hypothesis (1974) does not apply to porpoises caught in herring weirs in Canada. Further investigations using blood parameters and serology, histopathology, microbial cultures and samples for parasitic analyses can be carried out to examine the health of this population in more detail.

Mortality rates of porpoises in weirs were considerably less than the 39% estimate published by Smith *et al.* (1983). The overall mortality rate of porpoises in weirs was 9.5% of all recorded entrapments. This includes 18 porpoises that were shot. Seining porpoises from weirs does pose a risk to the animals, as mortality of porpoises for which a seine was attempted was 12%. This value is higher than overall reported mortality because it excludes animals that swam out on their own or were swept out. However, without a dedicated effort to remove porpoises during seining, mortality would probably be higher. The probability of mortality during seining can be further minimised by using the marine mammal seine, which has proven to be highly effective in the safe release of porpoises. Only 2.5% of porpoises that were seined out with the mammal net died, versus 18.4% that died in the herring seine net. The larger mesh size of the mammal seine allows herring to escape, leaving only porpoises behind in the seine. During seining, billows and pockets constantly form in the seine net due to the effects of tidal currents. If a porpoise becomes trapped in a pocket below the surface, it will die unless it can surface. The mammal seine is lighter than the herring seine and it floats to surface once the weights on the bottom of the seine are pulled up. This allows porpoises caught in billows beneath the water to swim in the net to the surface to breathe. The risk of mortality has been further reduced in recent years by placing swimmers in the weir to assist porpoises that become trapped in the folds and billows of the seine.

Mortality appears to be a random event among porpoises captured in weirs. There were no significant differences in sex ratio, length parameters or body condition of porpoises that survived the seining versus those that died. The mass of porpoises that died in weirs was slightly greater, but condition did not differ in blubber thickness or body girth, compared to porpoises that died in other human interactions in the Bay of Fundy. There was no relationship between body condition and the likelihood of mortality in porpoises trapped in weirs. We therefore conclude that the animals that perish during release attempts represent a random subsample of the population caught in weirs.

Some porpoises eat while trapped in weirs, but perhaps not at the same rate as animals captured in gillnets. The proportion of empty stomachs did not differ significantly between animals that died in weirs versus those that perished in gillnets. However, forestomach content mass of the weir sample was significantly less than that of the gillnet sample, indicating that weir-caught animals were either eating less or had not eaten for a longer period of time before death. Trapped porpoises have been observed to vomit when they become entangled in the herring seine. This behaviour will negatively bias measurements of stomach content mass. However, it is not known if a similar proportion vomit when they become entangled in groundfish gillnets. Porpoises in weirs were eating herring almost exclusively before they died, but it is not possible to infer if they were eating the herring before or after they entered the weir, as many animals are seined within 24 hours of entering a weir. The proportion of fresh prey items was significantly less in the weir sample than the gillnet sample, suggesting that animals in weirs had not fed as recently as animals in gillnets. However, the one weir-caught porpoise with fresh prey items in her stomach had been in the weir for at least 30 hours. She was a lactating female and fed while trapped. We conclude that porpoises trapped in weirs feed less than porpoises in open water, but animals with increased energy demands may have little choice and must eat while trapped.

Porpoise entrapment is most certainly correlated with herring abundance in weirs, as illustrated in Fig. 4. Entrapment numbers peak in August, concurrent with the highest herring landings from Grand Manan weirs. Since the implementation of the HPRP in 1991, herring landings per Grand Manan weir peaked in 1993, closely followed by 2001 (M.J. Power, Department of Fisheries and Oceans, St. Andrews, NB, Canada, pers. comm.). These years also corresponded to the highest numbers of porpoise entrapments (Table 1). 2001 was unprecedented in terms of porpoise entrapments and it was also anomalous in terms of amount of herring landed in June. Herring landings per Grand Manan weir in June 2001 were at least 2.5 times higher than any other recorded landings for June since 1978. Most harbour porpoises of the Bay of Fundy/Gulf of Maine population are believed to enter the Bay in the early summer, i.e. June and July (Gaskin, 1992; Palka *et al.*, 1996). Perhaps the unprecedented numbers of herring in weirs early in the season attracted more porpoises to the inshore waters around Grand Manan, where they remained for the 2001 season.

Certain environmental factors were also found to affect the probability of a porpoise swimming into a weir on a given night. Entrapment was related to tidal cycle (i.e. water depth at night), moon phase (i.e. moonlight level associated with moon phase) and time of year. Water depth varies with tidal cycle. High tides that fell during darkness as opposed to daylight significantly increased the probability (3.3:1) that a porpoise swam into a weir. High tides that occurred during the day had no effect on porpoise entrapment because porpoises have only been known to enter weirs during the night. This is most likely related to prey movement. During the day, herring are found in deeper water and it is only at night that they move inshore and become vulnerable to the weir fishery (Anthony, 1972). The Bay of Fundy experiences some of the world's greatest tidal amplitudes (> 10m) and weirs are built very close to shore with their entrances facing shoreward. Although none of the sea floor at the entrances of weirs monitored was ever exposed at low tide, the water level may have been shallower than some critical level for porpoises.

Lunar influence on light levels at night was also found to contribute significantly to the probability of weir entrapments. However, this variable was involved in a higher order interaction in the regression model, and must be interpreted by solving the regression equation for a given set of circumstances. The significance of lunar influence is not surprising, as herring behaviour is affected by light levels. Herring move furthest inshore on dark nights (Anthony, 1972).

Time of year also affects the probability of porpoise entrapments in weirs. An increase in local porpoise abundance is inferred from gillnet bycatches (Read and Gaskin, 1988; Trippel *et al.*, 1996). These authors found that the majority of bycatches in gillnets occurred in August. The HPRP is usually busiest during the last two weeks of August and mean date of entrapment events peak in August (Fig. 4). As previously mentioned, this also coincides with the highest herring landings from local weirs. It is therefore expected that porpoise entrapment will most likely occur when local porpoise densities and inshore landings of their primary prey are highest.

At present, we are only beginning to understand the nature of porpoise entrapments in herring weirs. It is not clear why 1995 was an anomalous year regarding the composition of porpoises or why 2001 was unprecedented in terms of numbers of entrapments. Nor is it clear why porpoises appear reluctant to leave weirs during the daytime. Further research on the ecology and behaviour of this species may help answer these questions.

The HPRP has become a successful, immediate mitigation solution for porpoise entrapment in weirs. However, like whale disentanglement, we view this as a triage procedure to minimise porpoise mortality in the short-term. Ultimately, we hope to develop strategies to reduce or eliminate porpoise entrapment altogether. The success of such long-term mitigation of bycatch requires the input and cooperation of the weir fishery.

Given the positive relationship established with weir fishermen, cooperation towards long-term mitigation of porpoise entrapment should be possible. As a first step, formal interviews with weir fishermen were conducted in the summer of 2003 to identify and discuss possible solutions. As with any such project, it will likely be some years before these mitigation measures can be implemented. In the mean time, continuation of the HPRP will provide opportunities to further study, monitor and help reduce incidental mortality in this porpoise population.

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