2.3. Measurement of by-catch

2.3.1. Diagnosis of by-catch as cause of death

When diagnosing the cause of death in a cetacean during post-mortem examination, a number of biological, toxicological, bacteriological and physical factors have to be taken into account (Kuiken *et al*. 1994). Even when the proximate cause of death is seemingly obvious, it is necessary to eliminate alternatives and identify contributory factors. Even an animal hauled onto a boat in a net may not have been killed by entanglement, since the carcass may have drifted into the net. Also, ill health may have contributed to the animal's failure to avoid entanglement. However, most animals brought on board a boat in a net will have died from entanglement.

The cause of death is less easy to determine in stranded animals. The diagnostic features indicative (or suggestive) of by-catch include lesions caused by contact with fishing gear or actions of fishermen when removing the animal from gear, lesions from immersion and evidence of feeding (in particular, recent feeding on the type of fish present in the net) (Kuiken 1994; Kuiken *et al*. 1994). Also relevant is the absence of evidence for other causes of death, e.g. due to bacterial infections, high parasite burden, high contaminant levels, or an epizootic (Hartmann *et al*. 1994; Tregenza & Collet 1998).

Lesions specific to interactions with fishing gear include the loss of a fin or the tail flukes, circumscribing wounds on the beak, head and fins caused by mesh entrapment and linear skin cuts. Abdominal incisions, deep penetrating wounds or abrasion around the tail stock may be caused, respectively, by fishermen slicing open the abdomen in order to make the carcass sink, and using a penetrating gaff hook or tying ropes around the tail stock to haul carcasses aboard (Hartmann *et al*. 1994; Kuiken *et al*. 1994; Siebert *et al*. 1994; Tregenza *et al.* 1994). Additional indicative lesions include scrapes on the skin of carcasses caused by close proximity to struggling fish and mechanical bruising and trauma. Occasionally carcasses will strand with ropes or netting still entangled on part of the body (Kuiken *et al*. 1994; Tregenza & Collet 1998).

The type of external lesions observed on stranded animals can sometimes be used to determine which type of fishery was responsible for by-catch. Thus, animals with a series of linear incision wounds and circumscribing wounds to the head were probably caught in gillnets whereas animals with net incisions and additional scrapes to the skin and/or fin avulsion and mechanical bruising are more likely to have died in trawls (Tregenza & Collet 1998). The latter injuries are often caused by animals becoming trapped in the pumps used to empty the cod-end of trawling gear (Hartmann *et al*. 1994). Additionally, the geography of a stranding, knowledge of local currents and fishing grounds and the stomach contents of carcasses can be used as circumstantial evidence when trying to identify which fishery was responsible (Cox *et al*. 1998; Tregenza & Collet 1998). However, circumstantial evidence of interactions with fisheries should be treated with caution. Cox *et al*. (1998) highlighted a correlation between mass cetacean strandings and a local shad (*Alosa alosa*) gillnet fishery, however, this fishery was placed in the lowest impact category specified by the MMPA of 1972 (Read 1994).

Lesions not specific to entanglement in fishing gear include haemorrhage, skull fracture (Kuiken *et al*. 1994) and internal bruising. Such injuries may result from the animal struggling to escape from a net, from the floatline or leadline of a net or even from being hauled overboard and landing on the deck (Tregenza 1994) and it should be noted whether they occurred post-mortem or not. However, such injuries could also result from other causes and, consequently, when observed alone, are not considered to be conclusive diagnostic features of by-catch - which may lead to underestimation of the extent of by-catch in stranded animals (Kirkwood *et al*. 1997; Tregenza & Collet 1998). Observed in juxtaposition with other forms of evidence however they lend weight to the deduction of by-catch as the cause of death (Kuiken *et al*. 1994).

Lesions specific to immersion are discussed by a number of authors and include: epicardial petechiae, froth in the bronchii, bullae in the lung parenchyma (Kuiken *et al*. 1994; Larsen & Holm 1994), incomplete collapse of the lungs, chyle in the ductus thoracicus (Hartmann *et al*. 1994) and blood-tinged watery fluid in the airways (Baker 1994). Such lesions are of interest when observed in association with conclusive evidence of by-catch, since it is not fully understood if the proximate cause of death in by-caught animals is drowning, suffocation or an unknown factor resulting from entanglement (Hartmann *et al*. 1994; Kuiken *et al*. 1994).

As yet there is some doubt as to whether cetaceans are voluntary breathers or reflex breathers like terrestrial mammals (Hartmann *et al*. 1994). In reflex breathers, a critical increase in the partial pressure of CO_2 in the blood stimulates sensors in the *medulla oblongata*, the hypothalamus, the pons and in the aorta and carotid arteries. Stimulation of these triggers inspiration which, if taking place underwater, would cause a terminal inhalation of water (Hartmann *et al*. 1994). However, if breathing is voluntary, no such reflex action will occur and death may not result from the inhalation of water but rather from suffocation – or the terminal depletion of oxygen in the blood – often termed “dry-drowning” (Hartmann *et al*. 1994; Larsen & Holm 1994). Consequently, while the presence of seawater in the lungs and other lesions of immersion may be indicative of drowning and probable by-catch, the absence of water in the lungs does not preclude by-catch as a potential cause of death (Hartmann *et al*. 1994; Kuiken *et al*. 1994).

A further complication for diagnosis of by-catch is the opening of the blowhole during *rigor mortis* in cetaceans (Baker 1994). Prior to, and after, *rigor*, the blowhole is usually closed but its opening during *rigor* exposes the upper airways to water, which may seep in. Consequently water in the airways of a cetaceans can not necessarily be considered evidence of drowning (Baker 1994). Additionally, tests of the chloride concentration to check for compatibility with sea water concentrations in blood-tinged water found in the upper airways of a dead cetacean proved inconclusive (Baker 1994).

Larsen & Holm (1994) examined 50 harbour porpoises after retrieval from set gillnets in a Danish fishery and, of these, water was found in the distal portion of the lungs in 49 animals. This water was found to contain dinoflagellates, diatoms, holothurians, foraminiferans and, on one occasion, an antenna from a crustacean. The water may have seeped into the lungs post-mortem, the organisms may have passed through the digestive system membranes and into the pulmonary system or they may have been taken into the lungs in the fine water vapour inevitably inhaled during normal inspiration (Larsen & Holm 1994). These authors concluded, however, that the former two hypotheses were unlikely owing to the improbability of water seeping so far into the lungs and the size of the organisms found and that the latter requires further scrutiny but also seems implausible.

In conclusion, the question remains as to whether water in the lungs can be considered diagnostic of drowning, and potentially of by-catch, in the absence of other supporting evidence. It appears that the presence of water in the distal part of the lungs is suggestive of a terminal inhalation of water. However, whether this could be considered as diagnostic of by-catch in the absence of other evidence is debatable (Larsen & Holm 1994). Further, lack of water in the lungs does not necessarily preclude the possibility of by-catch for cetaceans may suffocate or "dry-drown" when submerged (Hartmann *et al*. 1994; Larsen & Holm 1994; T. Paterson, pers. comm.).

Post-mortem evidence of feeding is an important feature when diagnosing by-catch for, not only is it suggestive of interaction with fishing gear, it is also indicative of an otherwise healthy animal (Hartmann *et al*. 1994; Kuiken *et al*. 1994; Tregenza & Collet 1998). Such evidence consists of the presence of undigested or partially digested fish remains in the cardiac region of the stomach (Cockcroft 1994b; Kuiken *et al*. 1994; Couperus 1997a; De Haan *et al*. 1997; Tregenza & Collet 1998; Morizur *et al*. 1999) and the presence of chyle in the lymph vessels (Kuiken *et al*. 1994). A full stomach is usually suggestive of a sudden death in a healthy cetacean – although not necessarily by-catch – while the lymph has a milky consistency after the consumption of fat-rich foods (Kuiken *et al*. 1994). Emaciated animals – those with a concave epaxial surface and an apparent 'neck' - are generally expected to have suffered from other ailments (Cox *et al*. 1998).

In summary, in the absence of direct evidence of by-catch, such as observation of entanglement in a net, by-catch is diagnosed during post-mortem examinations (Kuiken *et al*. 1994; Tregenza 1994). External examination for lesions specific to encounters with fishing gear are probably the most effective determinants of death by by-catch and it is sometimes possible to determine the type of fishing gear in which the cetacean was caught (Tregenza & Collet 1998). Lesions possibly caused by, but not specific to, fishing gear, lesions related to immersion, evidence of recent feeding and good body condition are all consistent with death due to by-catch but cannot be used in isolation to make anything other than a tentative diagnosis of cause of death.

2.3.2. By-catch estimation methods

Various difficulties arise in the estimation of numbers of cetaceans by-caught in a fishery, hence also in the evaluation of the efficacy of by-catch reduction methods. In addition to the usual problems encountered when trying to answer questions about marine mammals (e.g. related to their relatively low abundance and the inaccessibility of their habitat), the ever-changing nature of the fishing industry can make it difficult to ascertain if a problem exists, let alone quantify it. The perceived negative economic and social outcomes of restrictions on fishing activity that might be imposed to limit by-catch, the fact that the EU's Common Fisheries Policy is silent on the topic of cetacean by-catch, and the cryptic nature of the problem, also tend to discourage financial input into studies of by-catch (Northridge 1996; Pierce & Santos 2000).

Methods used to estimate by-catch rates, applied with varying success, include: observer studies, voluntary reporting schemes, mandatory reporting, strandings surveys, carcass salvage schemes, telephone and postal questionnaire surveys, interviews with fishermen and logbook analysis (Smith *et al*. 1983; Alling & Whitehead 1987; Clausen & Anderson 1988; Read & Gaskin 1988; Waring *et al*. 1990; Benke *et al*. 1991; Goujon *et al*. 1993; Fontaine *et al*. 1994; Kinze 1994; Lien *et al*. 1994; Lowry & Teilmann 1994; Sequeira & Ferreira 1994; Kock & Benke 1995, 1996; Bravington & Bisack 1996; Carlström & Berggren 1996; Northridge 1996; Palka *et al*. 1996; Trippel *et al*. 1996; Bisack 1997; Couperus 1997a,b; Tregenza *et al*. 1997a,b; Cox *et al*. 1998; Jaaman 1998; Tregenza & Collet 1998; Morizur *et al*. 1999; Northridge & Hammond 1999; Silvani *et al*. 1999; Norman 2000; Pierce & Santos 2000).

With all methods, a trade-off exists between the quantity and quality of data collected. Most efforts to measure the by-catch problem are subject to financial constraints and it is important to find the most cost-effective method, i.e. to achieve the highest level of accuracy and precision at the lowest financial cost (Northridge 1996; Palka *et al*. 1996).

Observer studies to monitor marine mammal by-catch evolved in parallel to those designed to monitor fish catches and generally are considered very effective (Northridge & Hammond 1999). However, they are also the most expensive method, with costs ranging from US $100 to $1,000 per day per boat (Northridge 1996). Ideally, at least 20% of the annual fishing effort should be monitored, observers should be trained before going to sea, and their responsibility should be to watch for cetacean by-catch alone. In reality this is rarely the case and ways to reduce the cost of observer monitoring programs include:

(a) use of volunteer observers, which tends to reduce data quality due to lack of training and commitment,

(b) extending observer duties to include observations of fish discards, which may result in a lower detection rate for cetaceans,

(c) sampling a smaller proportion of the fishing effort.

All of these approaches are likely to have a negative impact on data quality and, consequently, in the absence of sufficient funding for a comprehensive observer scheme, other approaches (as listed above) are often used.

These other methods are all cheaper than observer studies but are generally considered useful only when trying to determine whether a by-catch problem exists, for minimum estimates of by-catch rate, or to supplement results from more rigorous estimation procedures (Lien *et al*. 1994; IWC 1995; Northridge 1996).

Lien *et al*. (1994) compared the success of some of these methods, to see if any would be a viable and cost-effective replacement for observer studies. On conducting telephone interviews with fishermen, they found that 81.6% of fishermen were "very helpful". He found also that female interviewers obtained higher estimates than male interviewers, except those that had fishing experience of their own (Lien *et al*. 1994). On conducting second interviews, 64% of the fishermen interviewed gave different answers on the second occasion, including 84% of those who originally reported catching more than three porpoises. In the latter case, however, there was no bias toward estimates going up or down. In assessing the success of port interviews with fishermen, they again found most fishermen very helpful - although Couperus (1997a) experienced some reticence. Lien *et al*. (1994) also conducted a long-term experiment to check the ability of fishermen to recall their previous by-catch. When asked about by-catches in the decade ending in 1980, fishermen interviewed in 1980 reported a mean by-catch rate of 5.4 small cetaceans. When interviewed again in 1990, about by-catch in the same decade, the mean rate reported fell to 1.3 cetaceans. Furthermore, 38% of the fishermen – usually those who had reported high by-catch levels in 1980 – refused to hazard a guess. Consequently, the authors concluded that the results of such methods are highly variable. Nonetheless, as an alternative to making direct by-catch estimates from interviews, speaking to the fishermen prior to embarking on an observer study can be an effective way of determining which fishermen are likely to be co-operative and which vessels may have the greater by-catch problem (Pierce & Santos 2000). In 1990, Lien *et al*. (1994)

asked a number of fishermen to assist with a voluntary reporting scheme. As suggested by Jefferson & Curry (1994), and given that “economic incentives are critical to shaping human behaviour” (Shogren *et al*. 1999), it was felt that the path of co-operation would be smoothed by the offer of economic incentives. To monitor the effects of financial incentives, Lien *et al*. (1994) arranged a $10 payment per report to some fishermen, a $25 payment to others and no payment to 20 men. Those receiving the highest payment per report were the most conscientious in detailing their by-catch levels. Nonetheless, in a separate experiment, of 45 fishermen asked to maintain logbooks throughout their trips to record details on fishing effort, fish catch and by-catch, only 49% of fishermen returned their books despite a payment of $50 per book (Lien *et al*. 1994).

The introduction of mandatory use of logbooks (under the provisions of the US MMPA) in the NW Atlantic gillnet fisheries was also relatively unsuccessful with only 74 cetacean by-catches reported, as compared to an estimated 1,250 porpoises by-caught in the area (Northridge 1996). In 1984, fishermen were asked to volunteer for a research program in the Gulf of Maine, in which they were given MMPA permits that enabled them to fish anywhere provided that they handed in by-catch logbooks at the conclusion of the study. Less than a quarter of the local fishermen agreed to participate in the pilot study and only 60% of the logbooks were returned (Polacheck 1989).

Lien *et al*. (1994) concluded that by-catch estimates vary considerably with the monitoring method used and stated that (excluding observer programmes) port interview and logbook schemes resulted in the highest by-catch estimates, although both were expensive to run. In practise however, many authors use data from logbooks only as minimum estimates and would not consider logbooks and retrieval schemes a cost-effective approach to determining the extent of a by-catch problem (Polacheck 1989; Read & Gaskin 1990, Read 1994; Northridge 1996). As noted by Lien *et al*. (1994) the results from interviews with fishermen depended on the sex, demeanour and status of the interviewer and were generally better when the interviewer and fishermen were known to one another (see also Pierce & Santos 2000).

Strandings surveys are rarely used to directly estimate by-catch levels, although the results may be used to augment other by-catch monitoring systems (Cox *et al*. 1998). Many of the EU Member States have ongoing national or regional reporting schemes for cetacean strandings including France, Spain, Ireland, the UK, the Netherlands, Finland, Portugal and

Italy (e.g. Di Natale & Notarbartolo di Sciara 1994; Rogan & Berrow 1996; De Haan *et al*. 1997; Pierce & Santos 2000). These usually comprise of reporting networks which alert the relevant authorities to collect the carcasses and conduct post-mortems as necessary or when funding allows (Hartmann *et al*. 1994; Kuiken *et al*. 1994; Northridge 1996; Morizur *et al*. 1999; Northridge & Hammond 1999). Further to this, signatories to the Agreement on the Conservation of Small Cetaceans of the Baltic and North Seas (ASCOBANS) have made efforts to implement a "post-mortem co-operative" to encourage communication between those involved and to ensure that a standardised procedure is used on all stranded or by-caught animals[5].

Caution must be exercised when using strandings data to estimate by-catch rates since only a fraction of the animals killed in nets at sea are likely to strand (Moreno *et al*. 1993; Tregenza *et al*. 1997a). Tregenza & Collet (1998) tagged and released 22 porpoise carcasses within 50 km of the shore during an observer study so that they could be identified if found stranded. None of these animals were reported as stranded however. Moreno *et al*. (1993) demonstrated that all fresh carcasses sank immediately before resurfacing up to 55 days later. The carcasses tended to stay submerged for longer in colder water temperatures (Moreno *et al*. 1993) presumably due to slower decomposition rates. Given these observations, and the fact that most fisheries occur outside the coastal waters of national EEZ, it is likely that strandings represent only a small proportion of the animals by-caught at sea (Moreno *et al*. 1993; Tregenza & Collet 1998). It is also probable that the age and sex composition of stranded animals is biased by the social segregation of cetaceans (Cox *et al*. 1998; Karczmarski, 2000), with animals by-caught (or dying from other causes) nearer shore stranding more frequently. Thus strandings may be a poor indicator of the vulnerable components of cetacean populations.

The collection of by-caught carcasses from fishermen is also likely to produce a minimal estimate of the number of animals by-caught in a fishery or a region. Fishermen are rarely willing to co-operate with programs that could adversely affect their livelihoods (Polacheck 1989), both directly by losing time and space in the hold and indirectly by producing conclusive evidence of the by-catch problem. Also, the process of collecting, transporting, storing and examining the carcasses can be very expensive (Northridge 1996). Nonetheless, it

[5] See Appendix III: Website reference No.1

was thought that implementing a reward scheme could encourage the delivery of carcasses. Although Clausen & Anderson (1988) offered a reward equivalent to the value of 10 kg of herring for each cetacean handed in, the retrieval rate was still not high. They suggested that, if funds were sufficient, it might be beneficial to increase the payment for each carcass, although care has to be taken that cetaceans do not become a premium catch which is actively sought. On a positive note, carcass collection can be a good way of obtaining biological data on by-caught animals, to provide information on the sex and age composition of cetacean by-catch (Northridge 1996).

A number of researchers have used questionnaire surveys (Smith *et al*. 1983; Fontaine *et al*. 1994; Read 1994), either posting questionnaires to individual fishermen or sending batches of forms to local Fishermen's Associations (Smith *et al*. 1983). However, the return per unit effort is often very low and high costs are another disadvantage. It is also the case that the return rate varies over the course of the fishing season, since fishermen are most likely to fill in the forms when they are least busy. Thus, for example, surveys are more likely to be filled out in winter.

Voluntary and mandatory reporting schemes are generally unpopular with fishermen but incur very low research costs. Voluntary schemes rarely produce much data. Mandatory reporting, as applies in US waters (under the MMPA), is a good idea but is difficult to enforce (Northridge 1996). Northridge (1996) pointed out that fishermen consider they have enough forms to fill out already and resent the introduction of yet more regimentation, the freedom from which they have enjoyed in the past.

While all the methods described above can produce some useful data, those methods which place the burden of reporting directly onto the fishermen are all likely to be negatively biased and to thus provide only minimum estimates (Northridge 1996). A potential misconception may be that the lack of success is due to an unwillingness in the fishermen to co-operate. However, the higher return rate of questionnaires in winter suggests that a major problem is that full co-operation with such monitoring schemes impinge on potential earning time. Consequently, it is best to use an approach that takes up as little as possible of the fishermen’s time but ensures a good return per unit effort.

The most effective method of measuring by-catch rates is the observer study, in which trained observers (or “fisheries compliance inspectors”, Waring *et al*. 1990) onboard active fishing vessels directly record the number of cetaceans by-caught per unit of fishing effort (IWC 1995; Northridge 1996; Palka *et al*. 1996). Given data on the annual fishing effort in the specified fishery, the by-catch rate can, in principle, be extrapolated to estimate annual by-catch (Palka *et al*. 1996; Silvani *et al*. 1999).

A number of studies have used onboard observers, although the utility of the final results varies with the proportion of total annual fishing effort that is observed (see Goujon *et al*. 1993; Lowry & Teilmann 1994; Kock & Benke 1995, 1996; Bravington & Bisack 1996; Carlström & Berggren 1996; Trippel *et al*. 1996; Bisack 1997; Couperus 1997a; Tregenza *et al*. 1997a,b; Morizur *et al*. 1999; Northridge & Hammond 1999; Silvani *et al*. 1999; Pierce & Santos, 2000).

The first consideration when designing an observer program is the allocation of the observer effort, the sampling unit and the level of coverage required to ensure a low coefficient of variation. This point is considered in more detail in section 2.3.3. It is rarely possible to put observers on all the boats within a fishery and a representative sample of the fishery well may involve travel to remote areas (Northridge 1996; Palka *et al*. 1996). "Proportional" and "optimal" allocation of observer effort are the two main protocols used in these studies and the choice depends largely on the existing level of knowledge of by-catch in the area and the nature of the fisheries. Proportional sampling involves higher observer effort in areas of higher fishing effort to ensure that all parts of the fishery are equally represented. However, by-catch rates are not always proportional to fishing effort (or total fish catch) and individual by-catch events per fishing boat are quite rare (Fontaine *et al*. 1994). "Optimal" allocation therefore involves higher observer effort in areas where by-catch is known to be high (Palka *et al*. 1996). This is obviously not possible without prior knowledge of the by-catch rates and is thus rarely suitable for short-term or project-based studies (Northridge 1996). A possible approach to obtaining prior knowledge in a short-term study is to interview fishermen prior to the study to identify fisheries and areas with high by-catch rates (Pierce & Santos 2000).

Often the most effective sampling protocol is a combination of the two methods, i.e. placing more observers in areas or fisheries where by catch is known to be high, but using proportional allocation of effort within areas (Northridge 1996; Palka *et al*. 1996). As far as possible, boats are selected at random to ensure that the data do not all come from “environmentally aware” skippers, thus avoiding a negative bias in the results (Northridge 1996; Palka *et al*. 1996).

Skippers are often reluctant to take researchers onboard (Couperus 1997b) so, to ensure continued co-operation with observer studies or programs, it is suggested that a level of continuity be maintained in order to build a relationship of trust (Northridge 1996). It is also important, in building this relationship, that the fishermen are kept informed of the outcome of the data analysis and that they are told of any forthcoming recommendations resulting from observer studies on their boats. Such trust is essential if these programs are to be fully beneficial and confidentiality agreements should also be considered, to protect fishermen from the abuse of their local knowledge of good fishing grounds (Northridge 1996). Some authors even argue that compliance with observer studies and confidentiality agreements should be a legal requirement. Continuity however is again rarely possible in short-term or project-based studies and, combined with the lack of prior knowledge about by-catch in the region, short term studies can thus be difficult to implement (Northridge 1996).

It is recommended in many papers that the sampling be spatiotemporally stratified (Lear & Christensen 1975; Bravington & Bisack 1996; Palka *et al*. 1996; Bisack 1997, Pierce & Santos 2000) such that each combination of time and space constitutes one stratum and by-catch rates can be monitored and compared more effectively. Spatial stratification is usually informed by the recognised boundaries of fishery areas or the locations of the home ports of the fishing vessels, while the temporal strata are often seasonal, i.e. quarterly (Bisack 1997). Stratification varies between studies, areas and fisheries, in accordance with specific project aims, and can be complicated if the by-catch of more than species is being monitored (Palka *et al*. 1996).

In all observer studies, it is important to identify the available sources of data and decide upon an appropriate sampling unit for measuring by-catch (Tregenza *et al.* 1997a; Morizur 1999). Annual by-catch can then be derived by extrapolation (the "Ratio Method"; Palka *et al*. 1996; Silvani *et al*. 1999).

The most common sampling units used in observer studies on gillnet fisheries are the number of cetaceans caught per haul, boat trip, unit of the target species caught, km of net, day at sea or unit soak time[6] (Hall & Boyer 1986; Bravington & Bisack 1996; Carlström & Berggren 1996; Palka *et al*. 1996; Trippel *et al*. 1996; Bisack 1997; Tregenza *et al*. 1997a; Tregenza & Collet 1998; Northridge & Hammond 1999). Different sampling units are associated with different levels of accuracy.

Soaktime refers to the length of time a net is in the water while soaktime per km of net is often used as a measure of fishing effort and is expressed in units of net.km*hr (Palka *et al*. 1996; Tregenza *et al*. 1997a; Jaaman 1998). Given that hauling a net can take up to six hours (Goujon *et al*. 1993), the time that the net is in the water is taken to be the interval between the beginning of the shoot and the beginning of the haul (Jaaman 1998). The soaktime of gillnets ranges between six to 24 hours depending on the fishery and the target species (Read 1994; Sequeira & Ferreira 1994; Bravington & Bisack 1996; Carlström and Berggren 1996; Gearin *et al*. 1996; Trippel *et al*. 1996). The length of the net laid can be verified with GPS measurements (Tregenza *et al*. 1997a).

Soak time per km of net is the most commonly used sampling unit. However there is little point using this unit if there are no data available on the length of net laid per annum (Trippel *et al*. 1996; Tregenza *et al*. 1997a).

The sampling unit used when observing by-catch in trawls is usually the number of animals caught per tow (Tregenza *et al*. 1997b; Morizur *et al*. 1999) or, more precisely, per hour of towing (Morizur *et al*. 1999).

Details of the total annual fishing effort are often the most difficult data to acquire (Read 1994). However it is generally the case that researchers use all the sources of data that are available to them. These usually include official landings (numbers and biomass of catch) and fishing effort statistics, e.g. the number of fishing days per unit area (Julian 1997), fishermen’s logbooks (although these are often less reliable), market reports, portside interviews (Bisack 1997), and lists of registered vessels (Palka *et al*. 1996). Official data are obtained from bodies such as the Canadian Government's Department of Fisheries and Oceans, the Centre for Environment, Fisheries and Aquaculture Science (CEFAS) and the Scottish Executive Rural Affairs Department (SERAD) in the UK and ICES. Catch statistics

[6] See Appendix IV for details of sampling units

are officially submitted to ICES by 12 EU Member States and are entered into the STATLANT catch statistics database[7]. The official landing statistics in the north Atlantic are monitored by the Co-ordinated Working Party (CWP) which operates the STATLANT programme[4], set up in 1959 and reconstituted in 1995 (Gambell 1996). The general aim of the CWP was to improve the fishery statistics to ensure their accuracy and provide a better response to the increasing demand for the data (Gambell 1996).

A common method for estimating the annual by-catch rate is to measure the mean catch (numbers or biomass) of one net haul and to obtain the official annual total catch for the fishery. The total annual catch is then divided by the mean catch per haul to give an estimate of the number of hauls per annum which, multiplied by the number of cetacean caught per haul, results in an annual by-catch estimate (Bravington & Bisack 1996; Bisack 1997). Generally, the sampling unit chosen reflects the system used for measuring total annual fishing effort and it usually best to obtain data from more than one source and to compare the fishing effort estimates (Palka *et al*. 1996).

After deciding upon the sampling allocation and the sampling units to be used, it is important to design comprehensive and standardised data collection forms that list the parameters that need to be recorded. Most papers highlight the trade-off between quantity and quality, since if an observer is recording, for example, data on the cloud coverage during a haul then by-caught cetaceans may be missed. The responsibilities of the observers should ideally be kept to a minimum. However this is rarely the case (Tregenza pers. comm) and it is generally easier to encourage investment in observer projects that also monitor fish discards (Northridge 1996). This practise is often to the detriment of accuracy in the recording of marine mammal by-catch. During such multifaceted projects, observers are classed as “on-watch” when they are watching the haul for marine mammals only, and “off-watch” when they are simultaneously recording fish discards. The efficiency of “off-watch” observers is only 43% of that of “on-watch” observers. The US NMFS now use data only from dedicated marine mammal trips or include a correction factor in the calculations to account for the decrease in the off-watch observer efficiency (Bravington & Bisack 1996).

[7] See Appendix III: Website reference No. 2

The difference in efficiency between on-watch and off-watch observer results from the precarious hold that gillnets have on cetaceans when the nets are being hauled and the methods used to bring the catch aboard from the cod-end of trawl nets (Tregenza 1994; Northridge 1996; Morizur *et al*. 1999). Animals frequently fall out of gillnets as the nets are being hauled and, on occasion, are shaken out by fishermen to hasten the hauling process (Tregenza 1994; Northridge 1996). A study on the effects of such “drop-outs” and “shake-outs” demonstrated that, of 36 by-caught cetaceans, only 15 actually reached the deck of the boat (Bravington & Bisack 1996) - it is the 21 other animals which would most likely be missed by off-watch observers. A further problem for observers is that hauling of gillnets and trawling tend to occur mainly at night or dusk either to take advantage of vertical fish migrations or to avoid detection of illegal fishing activities (Clausen & Anderson 1988; Benke 1994; Read 1994; Tregenza *et al*. 1997a; Gill 1999; Tregenza pers. comm.).

Underestimates of by-catch may also be due to animals dropping out of the net at depth and/or too far from the boat for the observer to see them (Bravington & Bisack 1996). Given that cetacean carcasses are neutrally buoyant when fresh (Morizur *et al*. 1999), there is no easy way to quantify the former bias but the latter is considered to be less of a problem when hauling gillnets: the boat tracks the net as it is hauled and the weight of the net tends to ensure that only the portion of the net nearest to the boat is disturbed at any one time (Bravington & Bisack 1996).

Ideally, the data collected by observers in gillnet fisheries are: the location of the fishing operation, the length and type of gillnets set, the time taken to shoot and haul the nets, the number of dead animals seen in the nets, the viewing conditions, sea state, boat activity and speed and, if possible, cetacean abundance and behaviour (Goujon *et al*. 1993; Tregenza *et al*. 1997a; Morizur *et al*. 1999; Northridge & Hammond 1999; Silvani *et al*. 1999).

Optimal data collection during observations of trawling are similar but also include the duration, speed and depth of the tow, the size of the trawl mouth and the haulback speed (Morizur *et al*. 1999). Attempts are made to observe all hauls and, when the by-caught animals are brought aboard, efforts are made to record their length and sex, to conduct external examination for lesions related to by-catch, to collect biological samples for further analysis, and to record temperature (Goujon *et al*. 1993; Tregenza *et al*. 1997a,b; Morizur *et al*. 1999). Observers are also asked to note if the carcasses float or sink when discarded into the sea (Tregenza *et al*. 1997a). Other data are not considered to be essential (Northridge 1996).

Finally, it is important to ensure the safety of the observers whilst onboard, to ensure that they are familiar with being at sea, familiar with their responsibilities and that the fishermen are remunerated for any financial loss incurred, e.g. due to having to leave a crew member behind and for the observer's living expense (Northridge 1996).

2.3.3. Analysis of statistical power

One of the most fundamental considerations when designing a sampling programme is the sample size required. In reality, because it depends on the expected level of by-catch, it is difficult to determine in advance how many fishing operations should be observed to obtain a reliable estimate of cetacean by-catch. Given this, and the fact that funding and/or time are usually limited, most studies are not preceded by any formal analysis of statistical power. In some cases, having estimated mean by-catch rates, and given a knowledge of the statistical distribution of by-catches, an *a posteriori* estimate of statistical power is possible (e.g. Pierce & Santos 2000).

Simulations can be used to provide a good indication of the likelihood of detecting by-catch and the confidence that can be attached to any estimate.

If we assume that catching a single cetacean in a net can be modelled as a Poisson process, then it is straightforward to model the probability of seeing no by-catches during a set of observed fishing activities. In general, the probability of seeing r by-catches during a single sampling unit is given by:

$$P(X = r) = e^{-l} l^{r} r!$$

where λ is the mean by-catch per sampled unit of fishing effort.

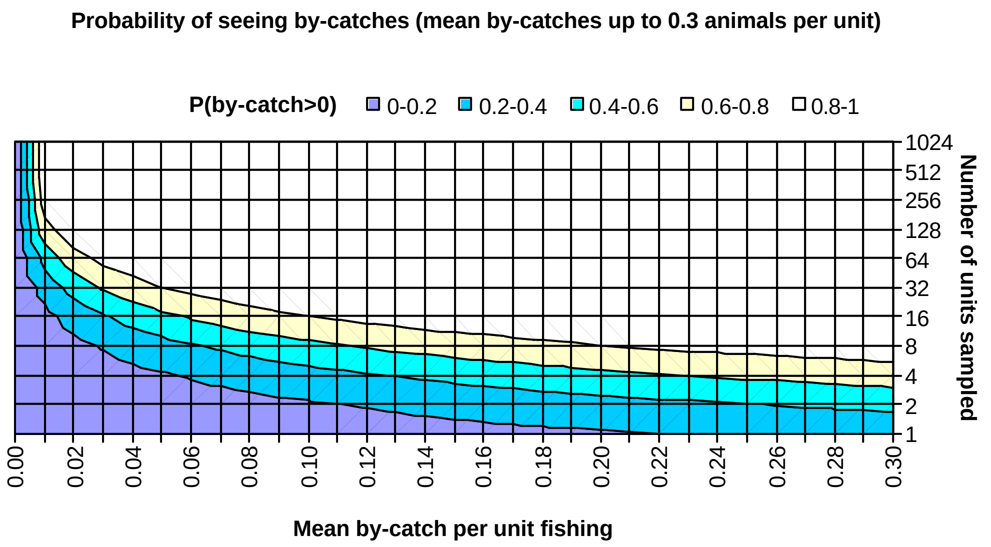
Since the terms l^{r} and r! both equal to 1 for X=0, the probability of observing at least one by-catch during N observed units of fishing activity is:

$$P\left(\sum_{N} X > 0\right) = 1 - P\left(\sum_{N} X = 0\right) = 1 - \left(e^{-l}\right)^{N}$$

As can be seen in Figure 2, for relatively high mean by-catch rates (1 animal by-caught in every 10 units of activity), even quite low sampling efforts offer a high probability of seeing at least 1 by-catch event. However, for lower mean by-catch rates, hundreds or even thousands of units may have to be sampled to result in the realistic prospect of seeing by-catches. Thus short-term studies on fisheries with low by-catch rates are quite unlikely to result in useful by-catch estimates.

A second simulation, based on a bootstrap re-sampling procedure, illustrates the median observed by-catch with 95% confidence limits, for a range of mean unit by-catches and sample sizes. As seen in Figure 3, for low mean by-catch rates, small samples will tend to underestimate the by-catch rate (as indicated by the median values) and confidence limits will be wide. As the mean by-catch increases, the sample size required to accurately estimate the average by-catch falls, but gains in precision continue to be achieved up to very large sample sizes.

Figure 2. Results of a simulation, based on a Poisson distribution of by-catches, to illustrate how the probability of seeing by-catches varies with the underlying average rate of by-catch and the number of fishing operations observed.



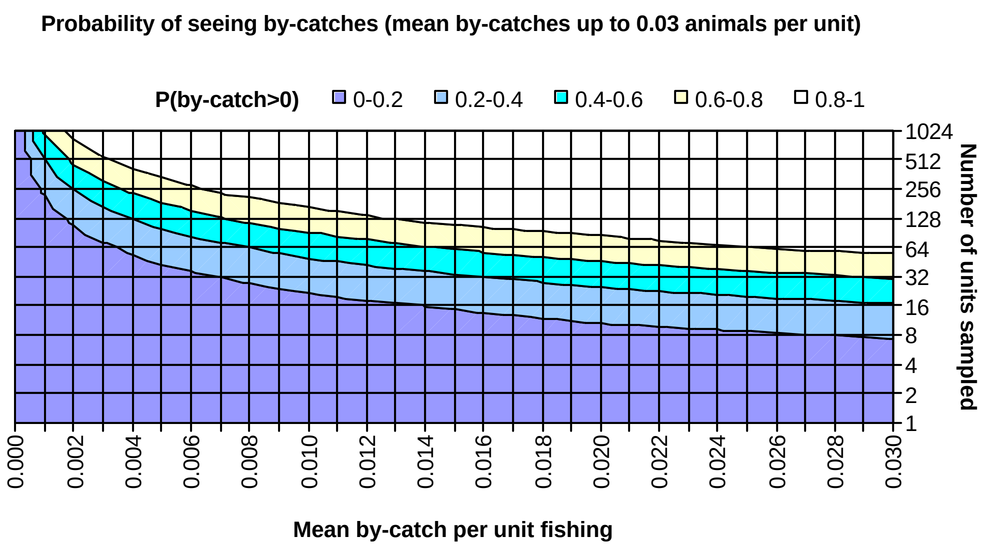


Figure 3. Results from a simulation, based on a Poisson distribution of by-catches, to illustrate how 95% confidence limits for estimates of by-catch rates will vary with the underlying average rate of by-catch and the number of fishing operations observed.