### *3.1. Development and application of by-catch reduction devices*

For the sake of clarity, the principles, technology and practicalities of BRDs will be discussed for gillnet and mid-water trawls separately.

#### 3.1.1. Gillnets

Cetaceans become entangled in fishing gears either because they cannot – or do not -detect them, because they do not perceive the gear as a threat or because the perceived feeding benefits outweigh the perceived risk (Goodson 1993, Goodson *et al.* 1994a,b; Goodson & Mayo 1995). Most by-catch reduction devices have been designed on the foundation of the former two hypotheses (Jefferson & Curry 1994) although efforts have ranged from direct attacks on cetaceans near nets (Fertl & Leatherwood 1997) to the application of highly sophisticated acoustic devices[16] (Kraus *et al.* 1995).

Some of the practical criteria that BRDs must meet were outlined by Dawson (1994) and Dawson *et al*. 1998):

(a) The capital outlay for fishermen must be kept to a minimum,

(b) The BRD must fit securely onto fishing gear and not impede its efficiency,

(c) The device must not serve to attract other predators such as seals,

(d) It must be low maintenance to minimise deployment costs and the effort required to police its use,

(e) It must be safe to handle.

Recently the methods most commonly tested for reducing entanglement in gillnets have involved the attachment of acoustic enhancement devices to nets. These can be divided into two categories: passive acoustic reflectors and active acoustic pingers (Goodson 1993; Goodson & Mayo 1995; Kraus *et al.* 1995; Gearin *et al.* 1996; Koschinski & Culik 1997; Nakamura 1998).

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

### 3.1.1.1. Passive Acoustic Reflectors

The objective of putting reflectors to gillnets is to increase the target strength of the less substantial parts of the net so that cetaceans will perceive the net as an impenetrable barrier (Goodson & Datta 1992, Goodson 1993). Without added substance, the only parts of a gillnet that have a significant target strength are the floatline, the leadline, the bridles, and the knots which tie the mesh together (Goodson & Datta 1992). The target strengths of the floatline and leadline are such that a bottlenose dolphin should be able to detect them from 60 m away (Hatakeyama & Ishii 1987) while that of the mesh is around 10 - 30 times lower (Hatakeyama *et al.* 1994). Consequently, the volume-scattered return that echolocation signals produce when aimed at the net were considered by Goodson & Datta (1992) to be insufficient to enable the animal to distinguish the net as an impenetrable barrier.

Practically speaking, reflectors meet most of the criteria for BRDs outlined by Dawson (1994) and Dawson *et al.* (1998). They are a low maintenance, one-time purchase requiring no active policing and are unlikely to attract unwanted attention to the net. These characteristics make reflectors a very attractive proposition, such that the transition to ‘dolphin-friendly gear’ could be very straightforward. A problem however is the effect they may on the efficient shooting and hauling of the net and on the geometry of the net when it is set (Goodson 1993; Goodson *et al.* 1994a).

Several authors have investigated the success of the reflectors as BRDs and have made efforts to quantify any disadvantages (Goodson 1993, Goodson *et al.* 1994a,b; Silber *et al.* 1994; Goodson & Mayo 1995; Koschinski & Culik 1997; Nakamura *et al.* 1998). Many of these studies found that the reflectors either made little difference to the by-catch rates in test nets or that the samples sizes were too small to afford any power to statistical comparison of the by-catch in test nets versus control nets (Silber *et al.* 1994; Koschinski & Culik 1997). Most concluded that reflectors were ineffective or warranted further study. Clearly, it is as important to document failures as it is to report the successes, since a process of elimination may help in the selection, or future development, of reflectors.

Koschinski & Culik (1997) measured the minimum distance that harbour porpoises maintained in response to two different reflector types suspended with various spacing. The first reflector was a standard cylindrical gillnet float with hemispherical ends and the second reflector was a spherical plastic "bobber". The minimum distance maintained by porpoises from the control floatline was 34 m while those from the two test lines were 33 m and 34 m respectively. During these observations, Koschinski & Culik recorded “logging behaviour”, in which porpoises remained at the surface of the water and scanned their heads back and forth. The occurrence of logging behaviour followed by a ‘non-avoidance reaction’ was similar for nets carrying reflectors and for control nets. The conclusion was that the reflectors were ineffectual as a deterrent (Koschinski & Culik 1997).

Many other studies followed similar protocols. Silber *et al.* (1994) tested “hukilaus” which consisted of a cork line with vertical lines of differing material suspended from it. These materials varied from beaded chain to polypropylene surgical tubing. Observing the number of ‘swim throughs’ by porpoises with each different hukilau, they concluded that none of the tested materials prevented the animals swimming through the hukilau.

Nakamura *et al.* (1998) conducted similar tests on a captive harbour porpoise and demonstrated that, when suspended lines supporting air-chambered reflectors were spaced 2 m apart, only 19.5% of approaches by the porpoise culminated in avoidance reactions. However when the reflectors were set 0.7 m apart, avoidance reactions followed 97.5% of approaches. These results were more promising, but the author pointed out that the avoidance rate markedly increased after the porpoises had had direct contact with the suspended lines, suggesting a learning process. Such contact would probably have been lethal under realistic circumstances. Additionally, no mention is given in the paper as to the order of the test sessions so it was difficult to assess whether the results could have been generated by a test order effect.

The failure of reflectors to reduce the likelihood of incidental entanglement under experimental conditions cannot be discounted. However, in these experiments, more consideration could have been given to the objectives of the reflectors, the mechanisms by which they work and the acoustic capabilities of the dolphins. The most comprehensive series of studies investigating reflectors were those co-ordinated by Goodson & Datta (1992), Goodson (1993), Goodson 1994, Goodson *et al*. (1994a,b) and Goodson & Mayo (1995) at Loughborough university, which refuted many of the results from previous studies. Before embarking on field tests of net enhancement devices, Goodson & Datta (1992) carried out extensive theoretical analysis of the wavelength-dependent resolving power of bottlenose dolphin echolocation, the bearing of the return echo received from different reflector shapes and the behavioural limitations imposed by the animal (Goodson & Datta 1992). They predicted that dolphins should be able to detect a gillnet from 12 m away (Goodson *et al.* 1994a). This distance is considerably shorter than those predicted by Au (1994) and Kastelein *et al.* (2000) (see section 2.2), however Goodson & Datta (1992) suggested that this detection distance was sufficient to allow the dolphin to avoid the net. As described earlier, the PRF of an echolocating dolphin varies with the stage of prey detection (Goodson & Datta 1992). However, Goodson & Datta (1992) go on to explain that the terminal PRF of a dolphin just prior to prey capture is variable and that prey seizure is often preceded by silence. They stated that physiological limits to the PRF may limit the benefit of continuing to echolocate upon prey when within 4 m of interception (Goodson & Datta 1992). Thus an echolocating dolphin may not be fully aware of its surroundings when making its final approach to catch a fish.

According to Goodson & Datta (1992) and Goodson *et al.* (1994a), reflectors incorporated into nets will be effective only when:

(a) The density of the material used is sufficiently different from that of seawater to enable it to halt the propagation of sound through the water,

(b) The reflector is of sufficient size to prevent the echoes from scattering,

(c) The shape of the reflector ensures that the reciprocal echo will be returned in the direction from which it came, irrespective of the dolphin’s angle of approach.

The peak click frequency of bottlenose dolphins, at 120 kHz, corresponds to a wavelength of approximately 12.5 mm. So “any echo producing target needs to be assessed in terms of this dimension” (Goodson & Datta 1992). For example, the knots adjoining the mesh are so small that they will only reflect a small proportion of the "ping" emitted by a dolphin and while the twine length will often exceed 12.5 mm, it is too unstable a substance to act as an effective target (Goodson & Datta 1992).

A further indication of the ideal size of a reflector is the maximum size of prey sought by dolphins. The largest prey item that a dolphin will swallow whole is between 35 – 40 cm in length. To avoid any acoustic similarity between reflectors and prey and thus permit discrimination between prey and reflectors, the size of the reflector must exceed that of the swim bladder of the dolphins’ largest fish prey item (Goodson & Datta 1992; Goodson 1993;

Goodson *et al.* 1994a, b; Goodson & Mayo 1995). Goodson & Mayo (1995) stated that, to achieve this, the reflector would need to have a target strength of at least 35 dB but made no mention of how this translates to reflector size.

There are problems associated with implementing each of Goodson & Datta's (1992) recommendations. Regarding the density of the reflector, an air/water interfaces offer the ideal density mismatch, as required to halt sound propagation in the water, but air pockets would tend to be crushed when deployed at pressure (Dawson 1994) and the additional buoyancy might affect net geometry (Goodson & Datta 1992). Metal/water interfaces are also effective but metals corrode in water, reducing the lifespan of the reflector (Goodson & Datta 1992). The shape of the reflectors cannot be too complicated for they may entangle or 'button-hole' the net as it is shot and hauled (SMRU 1999) whilst the 'perfect' spherical shape also causes problems with net deployment (Goodson *et al.* 1994b).

Goodson (1993) carried out a field experiment using a side-scan sonar, which emitted simulated broadband bottlenose dolphin clicks, to evaluate the return echo a dolphin would receive from a net enhanced with ellipsoid reflectors. He concluded that the reflectors substantially "filled in" the 18 m gap between the floatline and leadline, making the net 'appear' less penetrable. Drawbacks were that reflectors not only snagged the net on shooting but, due to air trapped in the reflectors, also affected net geometry.

The reflectors were tested with wild dolphins in the Moray Firth with promising, if not definitive, results (Goodson & Mayo 1995). Since it is illegal to set gillnets within six miles of the Scottish coast, and to minimise the risk to dolphins, 'dummy' nets without any actual mesh were used (Goodson *et al.* 1994b; Goodson & Mayo 1995). As in other studies, dolphins' reactions to floatlines, with vertically suspended lines bearing reflectors, were tested. Because the target strength of mesh is very low, exclusion of mesh from the experimental "nets" is not thought to have introduced any bias in the results. The dolphins in the study displayed avoidance behaviour in response to the reflectors, and such behaviour was observed as far as 100 m from the apparatus (Goodson & Mayo 1995). These results were more positive than were those from other studies. However, while the absence of the mesh may not have led to any bias, the absence of fish caught in the net may have resulted in an unrealistic simulation. It would be interesting to observe the deterrent effects of reflectors if struggling fish had also been strung from the floatline. Nonetheless, Goodson & Mayo's

(1995) study provided promising results, demonstrating the potential for reflectors to reduce by-catch by increasing the detectability of gillnets.

### 3.1.1.2. Active Acoustic Devices (Pingers)

Active acoustic devices or "pingers" are often referred to as the most effective method of by-catch reduction so far developed and their success has been demonstrated in a number of field studies (Kraus *et al.* 1995; Lien *et al.* 1995). Such is their potential that some European countries (e.g. Denmark) are soon to enforce their use in certain fisheries[17] while they already in use in some Category I[18] fisheries in the NW Atlantic (Trippel *et al.* 1999; Merrick 1999).

The objective in the application of pingers is essentially to make the net noisier and thus to increase the likelihood of cetaceans echolocating when around the net (Kraus *et al.* 1995). In a study carried out on the vocal behaviour of bottlenose dolphins in a foraging ground in the Moray Firth, out of 80 samples in which other call types were recorded, echolocation was absent 66% of the time (Spencer 1998). If by-catch of cetaceans occurs because they do not echolocate all the time when in familiar surroundings (Goodson *et al.* 1994a), attachment of pingers to nets should work by stimulating heightened awareness in the approaching animals (Dawson *et al.* 1998). Kershaw (1997) found that when pingers were in operation, the number of steady click trains emitted by porpoises in the vicinity remained the same but the number of click bursts decreased. The latter decrease was thought to have occurred because the animals responded to the pingers by swimming away from the nets and the directional click bursts were no longer recorded by the hydrophone.

Several types of pinger have been developed in recent years and some meet the BRD criteria better than others. In addition to the criteria applicable to all BRDs, it was suggested by Dawson (1994) that pingers will work only if:

(a) The sounds they produce are intrinsically aversive,

(b) They invariably encourage echolocation, and

(c) If cetaceans learn to associate the sound with danger.

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

[18] See Appendix IX for details of the MMPA fisheries categories

Concern has been expressed that animals may become habituated to the pinger emissions, so that pingers will function as BRDs only in the short-term (Kraus *et al.* 1995; Koschinski & Culik 1997; Trippel *et al.* 1999). Consequently it is important to ascertain which noises are directly aversive to cetaceans and how cetaceans react to particular sounds over the longer term.

During the CETASEL project (De Haan *et al.* 1997) the behaviour of captive harbour porpoises was observed in relation to nine different sound transmissions. In response to all the sounds, breathing rate, breathing force and swimming speed of the porpoises all increased, and the animals often appeared to move as far away from the source of the sound as possible. Sounds with fundamental frequencies of 7.5 kHz and 140 kHz caused the greatest changes in behaviour and sounds with higher source levels elicited a greater effect than those with lower source levels. Trippel *et al.* (1999) found that sounds with frequencies between 1 – 25 kHz produced variable results, while Koschinski & Culik (1997) demonstrated that captive harbour porpoises showed curiosity toward sounds with a fundamental frequency of 2.5 kHz but actively avoided sounds at 17.5 kHz. These data demonstrate that, as with reflectors, consideration of the acoustic facility of the cetaceans in question is necessary in order to design the most useful pinger.

Several authors describe studies applying pingers either to dummy nets or gillnets in real fisheries (Kraus *et al.* 1995; Lien *et al.* 1995; Gearin *et al.* 1996). The conclusions of most such studies are very positive, although in some cases small sample sizes afforded insufficient statistical power to confirm the results (Lien *et al.* 1995; De Haan *et al.* 1997).

Koschinski & Culik (1997) used pingers transmitting 77 beeps per minute at a peak frequency of 2.9 kHz and a sound source level of 115 dB. [It is not clear why pingers with a fundamental frequency nearer 2.5 kHz were used as opposed to the aversive 17.5 kHz, although eliciting curiosity is arguably as valuable as producing an avoidance reaction.] Three pingers were attached to a floatline, one 12 m from each end and one in the middle. Logging behaviour (as described above for the study on reflectors) was always followed by an aversive reaction, as seen in 92.4% of the approaches to the floatline. The porpoises kept a minimum distance of 133 m. The pingers did not affect the number of harbour porpoises using the area, nor was there any significant decrease in the number of avoidance reactions over time. Although the minimum distance was seen to decrease throughout the course of the experiment, Koschinski & Culik (1997) concluded that there was no significant habituation to the pingers.

Testing the success of pingers in Makah tribal gillnet fisheries, Gearin *et al.* (1996) showed that the cetacean by-catch per unit effort was 19 times higher in the control nets than in those nets with pingers attached. Each test net was fitted with 11 alarms at 16.6 m intervals and control nets were 10.5 times more likely to contain by-caught harbour porpoises than the test nets.

Dukane and Pice pingers are currently available on the market although each is still undergoing technical assessment (SMRU 1999). The Dukane pinger was developed in the USA and has been available since 1995 while the Pice pinger was developed more recently at Loughborough University in the UK and is marketed under license. The Dukane pinger requires new batteries every 30 days and, does not come with a self-activating immersion switch as standard. The Pice pinger has a battery life of one year, assuming six months of immersion, it has a self-activating immersion switch as standard and 'dummy' pingers are available at half the price for controls used in field trials. Controls in field trials of the Dukane pingers are usually real pingers with dead batteries and are therefore the same price to deploy (SMRU 1999). Dukane pingers emit broad band pings every 4 seconds with a fundamental frequency of 10 kHz (Kraus *et al.* 1995). Pice pingers emitted sounds every 20 seconds but no data were available on the fundamental frequency and source levels of the emissions.

Perhaps the most well respected field test of pingers was that conducted by Kraus *et al.* (1995) off New Hampshire on the north-east coast of America. To counter the lack of statistical power in previous studies (Kraus *et al.* 1995; Dawson *et al.* 1998), the NMFS formed a committee of scientists to consult about experimental protocol. On deciding that the study would yield definitive results only if carried out in fishing grounds reputed to have high by-catch levels, the panel agreed to sanction a study in a fishing ground that had been previously closed to sink gillnet fisheries. Statistical power analyses were carried out prior to the commencement of the study to ensure that the sample size would be sufficient to detect a 50% reduction in by-catch (Kraus *et al.* 1995). The study used Dukane pingers and the observer tests were "double blind" to eliminate bias, attaching pingers to all nets but with only half the nets carrying active pingers. The pingers did not activate until they were fully submerged, ensuring that skippers and observers did not know if they were setting an active net or a control (Kraus *et al.* 1995). During the study, 421 and 423 active and control nets were set respectively. Only two porpoises were caught in the active nets while 25 were caught in the control nets (Kraus *et al.* 1995). This result was statistically significant and proved to be a clear indication of the success of pingers in this fishery. Trippel *et al.* (1999) demonstrated a 77% reduction in by-catch in nets carrying pingers in a similar study. They speculated that Kraus *et al.* (1995) may have observed a greater reduction (92%) due to their pingers being closer together on the net. Both papers expressed concern that habituation may occur in the long-term and stated that their studies were conducted over too short a period to quantify this problem.

SMRU carried out a study to assess the effect of pingers on by-catch in hake fisheries in the Celtic Sea (SMRU 1999). They opted for the Pice pinger since it was cheaper to deploy than the Dukane pinger and the sounds produced were louder. The sound emitted by the Pice pingers is not audible to the human ear, thus helping to ensure successful implementation of a double blind procedure. However, problems were experienced: the active pingers were not triggered by the seawater as expected, the batteries failed or leaked and the dummy pingers swelled up and split while underwater. These inadequacies were considered to be specific to the particular product batch used. However, two problems persisted: the negative buoyancy of the pingers affected the geometry of the nets, unless additional buoyancy was added to the floatline, and shooting and hauling of the nets was impeded by the pingers, resulting from difficulties in attaching them to the floatline (SMRU 1999). Other studies have mentioned this problem but most fail to discuss it with the candour of the SMRU report. Ultimately the SMRU team tried five different methods of attachment, all of which failed to prevent the pingers "button-holing" the nets and taking too much over the stern during shooting (SMRU 1999). Finally they attached the pingers in bait bags tied tightly to the floatline. This method was the most satisfactory but still not ideal. Such problems should be taken into account for future developments to pingers but should not be allowed to distract attention from the general success of pingers as a BRD.

A discussion point in most of the papers that report the success of pingers is that it is rarely clear why pingers were successful. Kraus *et al.* (1995) pointed out that the prey of the harbour porpoise were able to detect the emissions of their pinger. Herring constitute 50% of the harbour porpoise diet in the NW Atlantic (Smith *et al.* 1983) and, although not the target species of the study fishery, herring by-catch in the test nets was 6.5 times lower than that in the control nets. Consequently Kraus *et al.* (1995) expressed uncertainty as to whether the pinger emissions were directly aversive to the porpoises or whether they simply drove the herring away and the porpoises followed. This “prey effect hypothesis” was rejected by Trippel *et al.* (1999) however, who found that pingers did not affect herring catches but that porpoise by-catch was still significantly reduced. The fundamental frequency of the pingers used by Trippel *et al.* (1999) was similar to that used in Kraus’s study although they were deployed for a shorter length of time (Trippel *et al.* 1999). Reduction of battery power in the Dukane pingers reduced the fundamental frequency of the sound emissions by about 4 kHz (Kraus *et al.* 1997) and it was suggested these lower frequency emissions may have been audible to the herring and thus responsible for the reaction absent in Trippel *et al.*’s (1996) study (Tripple *et al*. 1999). Trippel *et al.* (1999) did report significantly reduced catches of pollack in their study however. Pollack are not an important prey species for the porpoise so, while these data do not lend weight to the prey effect hypothesis, the species was one of those targeted by the fishery and consequently, the reduction in target catch was important (Trippel *et al.* 1999). Other reports describing successful deployment of active BRDs state that pingers had no effect on the fish catches (Lien *et al.* 1995). However, Gearin *et al.* (1996) reported an initial startle response in chinook salmon after which the fish resumed their normal behaviour.

In summary, reflectors have the potential to be a successful deterrent to cetaceans and, combined with low maintenance requirements and low cost, they are an attractive proposition. However, Goodson’s work highlighted the need for careful consideration of the species that the reflector aims to deter, and of the trade-offs between reducing by-catch and hampering net deployment.

Pingers appear to be a more successful means of reducing the incidental entanglement of cetaceans in fishing gear. Concern has been expressed that pingers may prevent cetaceans from using areas in which they are deployed (Laake *et al.* 1998). However, Trippel *et al.* (1999) pointed out that pingers sounds are not as loud as some natural underwater sounds. Neither Koschinski & Culik (1997) nor Trippel *et al.* (1999) found evidence that cetaceans were using their study areas less in response to deployment of BRDs. The biggest potential problem, however, is habituation in the long term. Indirect evidence that habituation is likely is provided by the fact that trawls are noisy and yet cetaceans are still by-caught in trawl.

However, apart from Koschinski & Culik (1997), who observed no apparent habituation, no studies have directly addressed this issue. It is apparent that longer-term trials of pingers in fisheries are now needed to resolve these issues.

In most of the trials reviewed above, BRDs have been deployed in the absence of other gear modifications. It is likely that this is mainly due to constraints of time and funding. However, a number of authors have highlighted that a positive correlation exists between by-catch and the soak time of gillnets (Kraus *et al.* 1995; Gill 1999). Additionally, there is a negative correlation between soak time and fish catch (Kraus *et al.* 1995). The longer the net is in the water the greater the likelihood that cetaceans will become entangled and the greater the opportunity for scavengers to feed upon the catch (Read 1994; Kraus *et al.* 1995; Gill 1999; INSRGCFP 2000). The soak time of gillnets ranges from six hours in Portuguese groundfish fisheries (Sequeira & Ferreira 1994) to as much as eight days in the sole fisheries in Denmark (Lowry & Teilmann 1994) although nets are more usually submerged for around 24 hours (Read 1994; Bravington & Bisack 1996; Carlström & Berggren 1996).

The by-catch rate may also be affected by the time of day at which the nets are set. It is noted in many papers that, as observed in trawling, by-catch in gillnets seems to occur more often at night than during the day (Smith *et al.* 1983; Benke *et al.* 1991). This may be due in part to the fact that most fishermen set their nets overnight to take advantage of vertical migrations of fish (Goodson *et al.* 1994a). However, higher by-catch rates at night are also seen in fisheries in which nets can be set either during the day or at night (De Haan *et al.* 1997).

It is likely that these modifications could help in curtailing by-catch when used in conjunction with other BRDs. It has already been shown that increasing the soak time decreases the value of the fish catch (Read 1994; Kraus *et al.* 1995) and it would be interesting to investigate the effect on fish landings of setting nets during the day.

### 3.1.2. Mid-water trawls

There are fewer hypotheses about the mechanisms of cetacean by-catch in trawls and consequently fewer suggestions about how to reduce by-catch. It is generally assumed that cetaceans know that the gear is present and are capable of out-swimming it (De Haan *et al.*

1997). Methods used to date to reduce by-catches have generally been borne of frustration by fishermen, who have chosen to "take the matter into their own hands" rather than wait for science to catch up with their needs! (Jefferson & Curry 1996). These range from the use of guns and firecrackers to scare the animals away (Fertl & Leatherwood 1997) to the tying of diesel-soaked clothes to the trawl (Silvani *et al.* 1992). One shrimp trawl fishery even applied the 'scarecrow' principle by placing a dummy dolphin carcass in the nets - which was initially successful, but only for a short time (Fertl & Leatherwood 1997).

Given uncertainty as to whether cetaceans are swept into the nets or whether they actively swim into the trawl mouth, it is difficult to know how to approach the problem. Generally however it is supposed that the animals actively swim into the nets, seeking food and aiming to take advantage of the catch (Perrin 1992; De Haan *et al.* 1997; Fertl & Leatherwood 1997). Furthermore, the impact of trawls has only recently been considered to be as important as that of gillnets (Fertl & Leatherwood 1997; Morizur *et al.* 1999). Consequently, the only serious by-catch reduction efforts explored so far are excluder devices, placed over the mouth of the trawls (De Haan *et al.* 1997).

### 3.1.2.1. Excluder Devices

The principle behind excluder devices for cetaceans is similar to that for turtle excluder devices (TEDs – sometimes referred to as Trash Eradication Devices), mandatory in shrimp fisheries in the Gulf of Mexico and Thailand, and seal saver devices (SSDs) developed in New Zealand squid fisheries (King 1999; De Haan *et al.* 1997). Both of these excluders involve a mesh placed over the cod-end of the trawl, through which the target species can pass, which deflect turtles and seals respectively through a gap in the net (De Haan *et al.* 1997). The main difference between these devices and similar modifications in mid-water trawls is that the latter are considerably larger than the demersal shrimp trawls (De Haan *et al.* 1997).

The CETASEL team (De Haan *et al.* 1997) tested four different excluder mesh panels, using three captive bottlenose dolphins. Prior to this study they had investigated the minimum mesh size needed to prevent a captive harbour porpoise from passing through a barrier. The porpoise would not pass through a net with mesh sizes 1.71 m x 0.54 m or 3.42 m x 1.08 m at all but eventually passed freely through meshes of 4.58 m x 1.44 m and 6.87 m x 2.16 m (De Haan *et al.* 1997). The excluder devices tested on the bottlenose dolphins varied from vertical panels with parallel ropes to combinations of ropes, reflectors and meshes. It was intended that the smaller meshes would deflect the dolphins up through the larger meshes which, in practice, would steer them away from the mouth of the trawl. None of the excluder devices were successful however and the animals simply swam through the meshes (De Haan *et al.* 1997). These results are not necessarily unexpected for the data suggesting the animals would not swim through a smaller mesh referred to the harbour porpoise and there is little evidence to suggest that porpoises are caught in trawls.

De Haan *et al.* (1997) showed that the excluder device had no effect on the geometry of a scale-model trawl. However, when the devices were tested on a life-size trawl, the geometry was significantly altered, reducing the efficiency of the net. Catches improved after adjustment but did not reach the biomass of catches in unmodified gear.

It is commonly observed that by-catch rates in trawls are far higher at night than they are during the day (Goodson *et al.* 1994b; Read 1994; Couperus 1997b; De Haan *et al.* 1997; Fertl & Leatherwood 1997; Tregenza & Collet 1998; Morizur *et al.* 1999). Much trawling occurs mainly at night and the fishermen use often lights as lures (Sequeira & Ferreira 1994) which are thought to attract cetaceans (De Haan *et al.* 1997). As with gillnets, it may be worthwhile investigating the costs (e.g. in reduced fish catches) of trawling during the daytime rather than at night. In conclusion however, we can only concur with De Haan *et al.* (1997) that more work is required to establish the mechanism of by-catch in trawls before effective BRDs can be designed and tested.

### 3.1.3. Conclusion

Many papers conclude with an outline of the problems associated with different BRDs. Comments vary from the downright negative suggestion that BRDs are ineffective and warrant no further investigation (Dawson 1994) to mildly cautious statements that more work is required before conclusions can be drawn (Jefferson & Curry 1994,1996; Goodson & Mayo 1995; Kraus *et al.* 1995; Koschinski & Culik 1997; SMRU 1999).

There are a number of BRDs in the early stages of development (Goodson & Mayo 1995; Kraus *et al.* 1995; SMRU 1999), which have shown varying degrees of success in localised field tests but not been tested on a large scale. However, even studies demonstrating high success rates with BRDs, with statistically significant results, such as those described by Kraus *et al.* (1995), conclude with discussions of the uncertainties about why their products worked so well. While it is important to continue to test alternative BRDs, and determine the mechanisms by which BRDs succeed, there has to come a point when procrastination ends and the results of comprehensive studies such as those of Goodson & Datta (1992), Goodson *et al.* (1994a,b) and Kraus *et al.* (1995) are put into action.

It seems probable that caution is exercised due to the investment required to launch a BRD commercially, and the inherent risk of a BRD failing to work - as was demonstrated on a small scale in the SMRU (1999) report. Whilst we are not advocating hasty decisions, perhaps the time has come to take stock of what devices we have available and to channel developmental work into maturing the most promising products.

While the politics and logistics of product development, testing, and introduction into the commercial environment are recognised here, we prefer to take a more simplistic approach. If evidence exists to suggest that BRDs can be successful, action should be taken to test their success in different fishing grounds and to implement their use in relevant fisheries. The effective reduction of by-catch serves the purpose not only of protecting cetacean populations but also helps the fishing industry and individual fishermen. As many publications point out, by-catch is costly to the industry in terms of damaged gear, lost fishing time, loss of catch and bad publicity. On a larger scale, it can lead to area and seasonal closures and even moratoriums on use of certain gear types (Consiglio *et al.* 1992; Perrin 1992; Silvani *et al.* 1992; Lowry & Teilmann 1994; Read 1994; Fertl & Leatherwood 1997; Trippel *et al.* 1999; Pierce & Santos 2000).

It is paradoxical that reduction of cetacean by-catch could alleviate financial losses to the fishing industry but the development and testing of BRDs is apparently inhibited by lack of funding. Management of the by-catch problem is of course as much a political issue as it is one of technological development. However, it should be possible for scientists, the fishing industry and the legislative bodies to work towards a common goal: reduction of by-catch with minimal impact to the economic viability of the fishing industry at national and local levels.

The establishment of TRTs in the NW Atlantic provides a simple model for a multisectoral approach to dealing with the single issue of by-catch. Although this is not necessarily the best solution, in Europe, a fundamental shift is needed in the way fisheries management is approached. We highlight the need for explicit recognition of multiple objectives when evaluating consequences of alternative management options, rather than a naive system of deriving Total Allowable Catches (TACs) based on fish stock abundance and making *ad hoc* adjustments to appease other interest groups (c.f. Hilborn & Walters 1992). This is in tune with suggestions coming from numerous other sources, taking on board concepts such as subsidiarity and co-management, as embodied in forums such as the (embryonic) North Sea Commission. Thus, given certain ground rules (such as an upper limit on cetacean by-catches, preferably enshrined in legislation rather than relying on voluntary codes), all interest groups work together to achieve the desired economic, social, ecological and environmental outcomes of fishery management.