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A pan-European valuation of the extent, causes and cost of escape events from sea cage fish farming

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ABSTRACT

As part of an EU funded 7th Framework project, *Prevent Escape*, a programme of research was undertaken to document the extent, size and knowledge of the causes of escapes from marine fin fish farms in Europe over a three year period. Escape incidents were identified and assessed through questionnaires across the 6 countries (Ireland, UK, Norway, Spain, Greece, and Malta), and other data supplied by the Norwegian Fisheries Directorate and the Scottish Aquaculture Research Forum. A total of 8,922,863 fish were reported to have escaped from 242 incidents. Of these over 5 million occurred in two catastrophic escape incidents. Sea bream accounted for the highest number of escapes at 76.7% followed by Atlantic salmon at 9.2%. Of the 113 Atlantic salmon escape events, almost 75% were due to structure failure or operational error. Almost 50% of cod escape incidents were due to biological causes e.g. biting of nets. The nominal costs of escapes as calculated by value at point of first sale were very substantial, estimated at approximately €47.5 million per annum on average over the study period. Of this €42.8 million was for annual cost of losses of sea bass and sea bream in the Mediterranean and €4.7 million for losses of salmon in northern Europe.

1. Introduction

Knowledge of the extent and causes of escape incidents from sea-cage fish farms varies greatly from country to country across Europe. Several countries, such as Norway, Scotland and Ireland, have legislated reporting requirements whereby farmers are obligated to report escape incidents, their size and cause and when they occur. In contrast, Mediterranean countries have no such requirements; thus no statistics are available on the number of escapes or the underlying causes of escapes (Dempster et al., 2007).

Norway has the most comprehensive record of escapes, dating back approximately 15 years for salmonids and 5 years for Atlantic cod. A total of 722,000 and 963,000 salmon and rainbow trout were reported to have escaped from Norwegian farms in 2005 and 2006, respectively (Norwegian Fisheries Directorate, 2007). The real number of escapes has by some been estimated to be considerably greater (Torrissen, 2007) because not all escape incidents are believed to be reported.

Substantial escape events of salmon have also occurred in other major salmonid producing countries, such as Scotland, Chile and Canada (Naylor et al., 2005; Soto et al., 2001). Over one million salmon were reported to have escaped from Scottish farms during the period from 2002 to 2006 (Thorstad et al., 2008). The proportion of Atlantic cod that escape is high in comparison to salmon (Moe et al., 2007). In 2005 and 2006, 213,000 and 288,000 cod, respectively, escaped from Norwegian farms.

While no official statistics on the extent of escapes exist for Mediterranean countries, data available from companies that insure fish farm businesses indicate that escapes are a significant component of economic losses claimed by farmers (EU FP-6 ECASA project; www.ecasa.org.uk). From 2001 to 2005, 76 claims accounting for 36% of the total value of all insurance claims made by fish farmers in Greece were due to stock losses from storms, while damage to farm equipment due to storms accounted for 19%. A further, 39 registered 'predator attacks' resulted in claims of 10.4% of the total value of all insurance claims, although the proportion of this which relates to stock loss or cage damage is unknown. The existing evidence suggests that escapes are a relatively frequent occurrence on a pan-European scale.

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Escapes are caused by a variety of incidents related to farming equipment and their operation. Reports by fish farming companies to the Norwegian Fisheries Directorate following escape events during the period from 2001 to 2006 indicate that escapes can be categorised broadly into structural failure (52%), operational related failure (31%) and biological and/or other causes (17%). Structural failures may be generated by severe environmental forcing in strong winds, waves and currents, which may occur in combination with component fatigue or human error in the way farm installations have been installed or operated (Jensen, 2006). Operational related failures leading to escapes include collisions with boats, incorrect handling of nets or damage to nets by boat propellers. The risks to farm installations from the marine environment largely come from exposure to waves and currents (Lader and Fredheim, 2007; Lader et al., 2008) and from collisions with seagoing vessels. The further offshore a farm is located, generally the more exposed it is to the elements, thus increasing the risk of escapes.

There is growing evidence that with cod the reasons for escape differ from salmon. This stems from behavioural variations in captivity. Firstly, cod bite the net and might thus increase wear and tear and contribute to the creation of holes (Moe et al., 2007). Secondly, cod show more pronounced exploratory behaviour than salmon and might thus have a higher probability of discovering small holes in the net (Damsgård et al., 2012; Hansen et al., 2009).

Official statistics and other sources of information which apportion causality to escape events provide little explicit detail to support technological development that will improve farming equipment and modify operations to avoid mistakes that cause escapes. Categorisation of causes may also be inaccurate, as causes are rarely investigated in detail (Valland, 2005). Such detail only comes through thorough investigation of the causes of escape incidents on a case by case basis (e.g. Rist et al., 2004).

This study documents the extent and costs of escapes and presents the biological, technical and operational causes giving rise to escapes of fish from sea-cage fish farms in marine waters in 6 European countries over a three year period.

2. Materials and methods

A specific methodology was applied across all 6 countries (Ireland, UK, Norway, Spain, Greece and Malta) in order to ensure comparability of results. The methodology was made up of the following components and actions:

1. Consult with industry and relevant agencies through a confidential questionnaire and follow-up interviews to gather information on methodologies and technologies currently used to on-grow finfish in the marine environment.
2. Gather available existing information on the extent, size and knowledge of the causes of escapes from national reports and other published data.
3. Conduct detailed assessments of the explicit technical or operational causes of escapes at sea-cage fish farms throughout Europe by direct assessment of known escape events at industrial fish farms, by way of site visits and interviews.
4. Establish the total economic cost of escape events through a cost evaluation using both available data and through direct gathering of data by way of interview.

The questionnaire was divided into 4 main sections:

Section 1, Infrastructure, was designed to gather data relating to materials used and design of floater types (i.e. cage structures), nets and mooring systems. Section 2, Maintenance, was aimed at establishing if the site employed maintenance management systems for the infrastructure and how these maintenance systems were carried out. Section 3, Escapes, was used to establish if there were escape incidents and if so, how many and if there was further information available on the events. This section also required the farmers to give an estimate of the cost of the stock loss and clean-up operations to the business. Section 4, Environment, was used to gather the environmental data available for the sites in question. The full methodology, including details of the questionnaire and interview processes used, has been published (Dempster et al., 2013) as part of a compendium of outputs from the Prevent Escape project.

National statistics were consulted where they were available (Anon., 2012; Browne et al., 2007; Jensen et al., 2010). In addition other sources of national data were accessed including government reports (www.scotland.gov.uk/Topics/Fisheries/Fish-Shellfish) and studies. Finally EU and FAO (Barazi-Yeroulanos, 2010; http://www.globefish.org/homepage.html) statistics were used where appropriate. The average size of fish at harvest was derived from a combination of national statistics, where available, and from information received (*pers. comm.*) from the relevant producers organisations. Results for nominal costs of losses are reported both as a cost per kilogramme and as an estimated total cost based on the average harvest weight of the relevant fish stocks.

In each of the participating countries a series of follow-up visits with industry were conducted. These considerably added to the detail and availability of data. Each partner identified 5 escape events in their region which were to be investigated in greater detail. In some countries it was necessary to focus on a few companies which had encountered several escape events.

The cost of escapes from marine fish farms can be evaluated in a number of different ways. Depending on the starting point, the parameters and paradigm used to quantify costs can be very different. Many of the concerns held over the impacts of escapees relate to potential negative impacts on the surrounding environment. If such impacts were well described they could be assigned a cost, but doing so would be fraught with multiple assumptions based on very scant data. There is however a very pragmatic and relevant basis for assigning a cost to aquaculture escapees; the measure of lost income at point of first sale due to loss of stock due to escape incidents. As part of the FP7 project *Prevent Escape* (FP7-KBBE-2008-2B-226885) an exercise to evaluate the cost of escapees in partner countries was undertaken. The basis of this exercise was to calculate the numbers of fish escaping and to assign them an appropriate value at point of first sale in order to arrive at a nominal cost of losses which would facilitate comparison across a number of different farmed species, a range of management regimes and across a wide geographic area encompassing both northern Europe and the Mediterranean region.

A specific methodology was developed and applied across all participating countries in order to facilitate comparability of results. In the development of this methodology cognisance had to be taken of the quality and extent of available data and information. Where possible, published figures, such as FAO fisheries and aquaculture statistics, together with nationally available official figures were relied on as a basis for calculations. This data was combined with the outputs from the *MAP Escape* component of the Prevent Escape project (Dempster et al., 2013) to derive a nominal cost of losses with a defined set of assumptions and limitations. The analysis was carried out for six countries; Ireland, Norway, Scotland (UK), Spain, Greece and Malta.

3. Results

A total of 242 escape incidents were identified through questionnaires, which were completed across the 6 countries, and using other data supplied by the Norwegian Fisheries Directorate and the Scottish Aquaculture Research Forum. The causes given for these events are shown below in Table 1. Some of the events were as a result of a combination of causes. The majority of escape incidents related to net damage due to predator attacks and abrasion. Storm damage or weather was also a common cause. However, it was not clear from the responses obtained whether the storm losses were due to net, mooring or floater damage.

Table 1
Causes of escape incidents and numbers of escaped fish as identified by questionnaire.

Species	Total		Structural		Biological		Operational		External		Unknown	
	No. of incidents	No. of escapes	No. of incidents	No. of escapes	No. of incidents	No. of escapes	No. of incidents	No. of escapes	No. of incidents	No. of escapes	No. of incidents	No. of escapes
Atlantic Salmon	113	820,158	40	678,279	5	6758	47	88,065	3	13,194	18	33,862
Cod	61	457,005	6	16,466	38	118,974	6	11,839	3	180,717	8	129,009
Sea bass	15	599,600	9	540,000	5	52,100			1	7500		
Sea bream	52	684,6100	22	6,181,900	25	604,000	1	20,000	2	25,200	2	15,000
Meagre	1	200,000	1	200,000								
Totals	242	892,2863	78	7,616,645	73	781,832	54	119,904	9	226,611	28	177,871

A total of 8,922,863 fish were reported to have escaped from the 242 incidents. Sea bream accounted for the highest number of escapes at 76.7% followed by Atlantic salmon at 9.2%. Of the 6,846,100 sea bream reported to have escaped, two of the incidents accounted for 1.9 and 3.8 million fish, respectively. It should also be noted that three of the escape incidents relating to sea bream had unknown numbers of fish reported.

Of the 113 Atlantic salmon escape events almost 75% were due to structure failure or operational error. Almost 50% of cod escape incidents were due to biological causes e.g. biting of nets. One major incident involving a trawler accounted for 34% of all cod escapes over the selected period.

The majority of escape incidents (Fig. 1) relate to the enclosure netting, with biting of nets being most common, while the underlying cause for 67% of the number of fish escaping (Fig. 2) was mooring failure. Net biting (Fig. 3) was responsible for the highest proportion of incidents of hole in the net followed by predator damage. This net biting is a behavioural characteristic of both cod and sea bream. While the type of predators causing net failure differs from the Atlantic (e.g. seals) to the Mediterranean (e.g. dolphins/wild fish) the outcome is the same.

For Ireland, Norway and Scotland it was possible to obtain official figures for the total number of escapes. These were used as a basis for calculating the value at point of first sale of the escapees. The number of escapees per annum was multiplied by the average harvest weight in kilogrammes for farmed salmon in each country and the result was multiplied by the average value per kilogramme of salmon sold, for that year in each country. Average weight at harvest and average first sale prices were obtained from representative organisations, national statistics and other recognised sources of such commercially sensitive information. The results are presented in Table 2. The total value of escaped salmon in terms of first sale value was estimated at €4.7 million per annum.

For Malta, Spain and Greece official statistics on escapes are not compiled. In these countries, the results obtained in the questionnaire and supplemented by follow-up investigations and interviews were used as the basis for calculating the number of escapees. The number of escapees recorded was taken as a representative subsample and the estimated total calculated by reference to the proportion of the total production sampled (Table 3). For example if 20% of the farm production was sampled the resulting figure was raised by a factor of 5 to give an

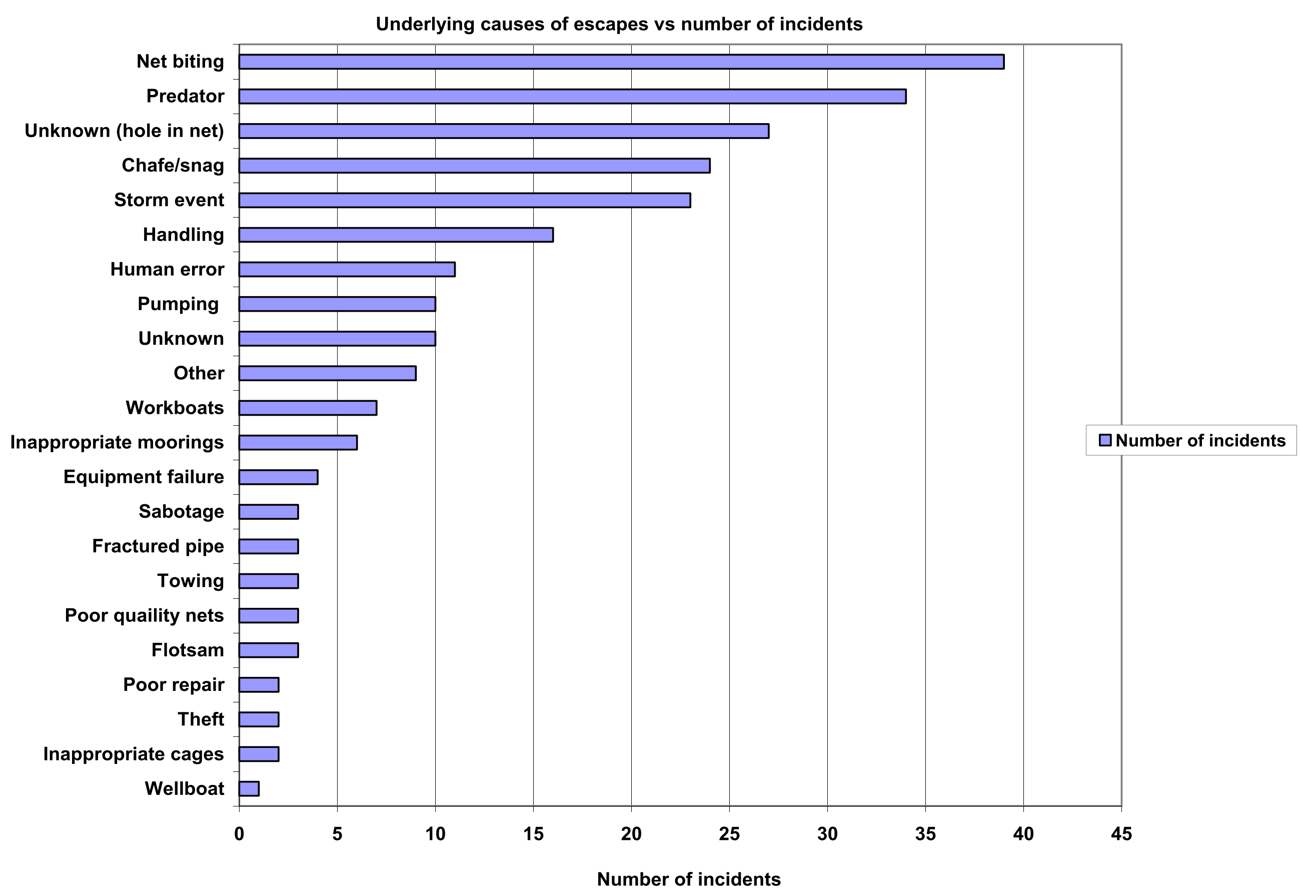

Fig. 1. Underlying causes of escapes versus number of incidents.

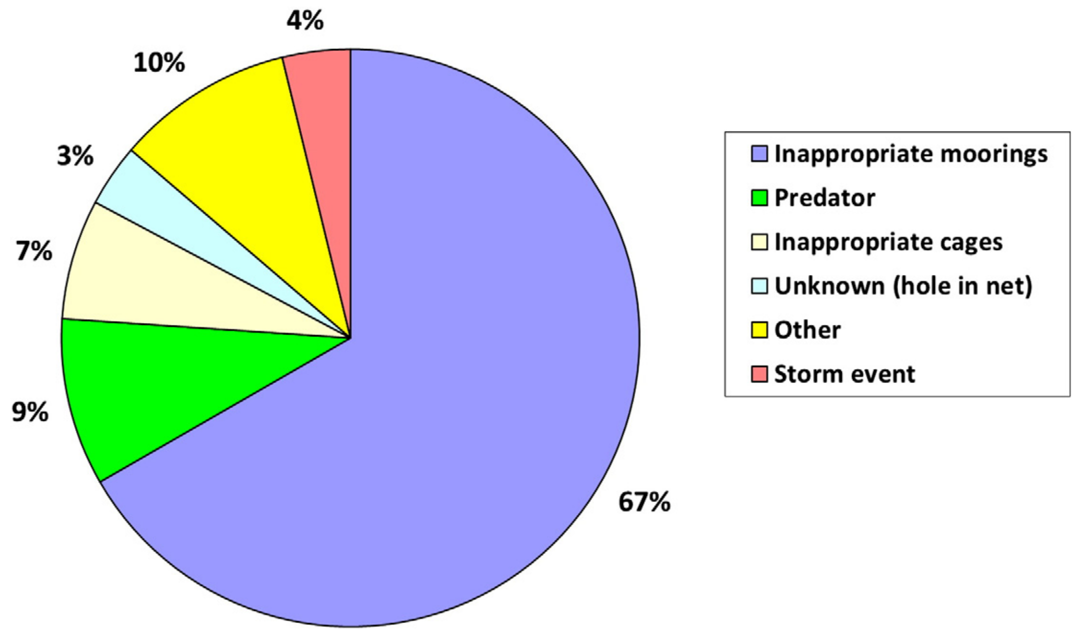

Fig. 2. Percentage number of escapees, attributed to 6 main underlying causes of escape incidents.

estimate of the national total. Where the subsample was large, such as Malta (>60%) there is a higher confidence regarding the accuracy of the resulting estimate than where the sample represents a smaller proportion of the national production. FAO and Globefish statistics were used to calculate value at point of first sale and the size at point of sale was set at 500 g.

Over a three year period a total of 242 escape incidents were documented representing a variable proportion of the farms in operation in each country. This percentage varied from a low of 20% to a maximum of 75%.

In northern European countries, national statistics are available on total escapes due to mandatory reporting requirements. Where available these were used as a basis for calculations. Results indicate that the cost to the industry in terms of loss of sales revenue at point of first sale is in terms of tens of millions of euro per annum. The Prevent Escape partners are currently carrying out a scoping exercise to attempt to produce a validated figure for an average annual cost for the European industry in terms of euro per tonne of licensed production. This figure could then act as a baseline to measure improvements in efficacy of containment against, and to derive cost–benefit metrics for, improvements in containment.

4. Discussion

Out of a total of almost 9 million escapees recorded in the study period over 75% were accounted for by escapes of sea bream. Of these over 5 million occurred in two catastrophic escape incidents. The most significant factor in terms of number of fish escaping (Fig. 2) was mooring failure. In terms of numbers of fish escaping this factor accounts for over two thirds of all escapees recorded in the study.

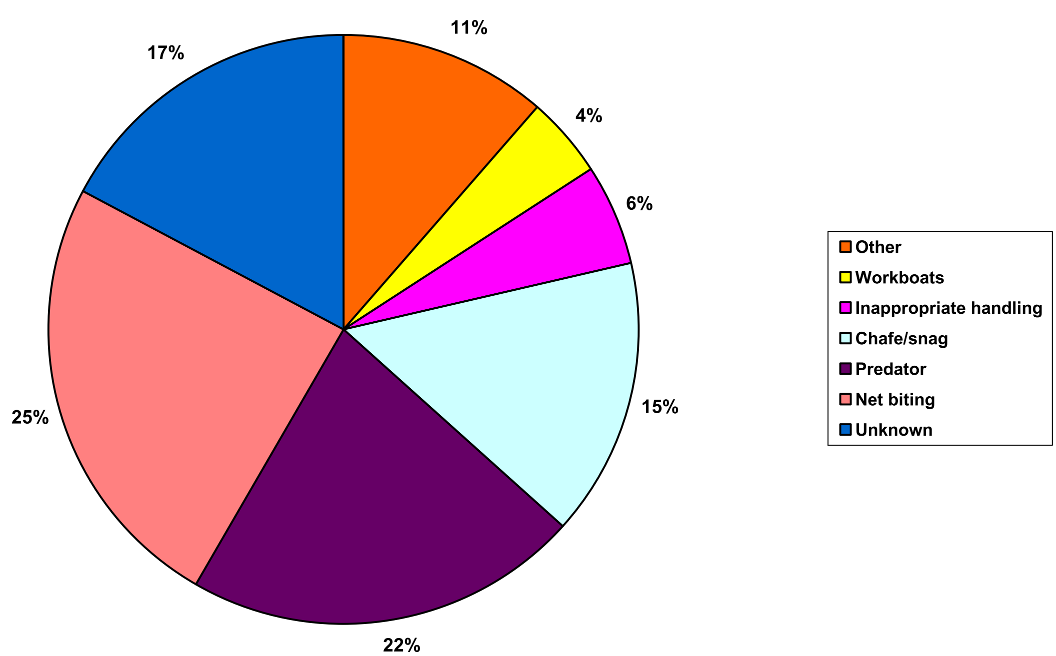

Fig. 3. Overall causes of hole in net. Number of incidents as a percentage of total incidences of hole in net.

Table 2
Nominal cost of losses Norway, UK and Ireland.

	2007	2008	2009	
Nominal cost of losses Norway				
Total value of production (€ million)	1915	1925	2295	
Losses (nos. of fish)	246,488	76,387	180,407	
Av. price/kg €	3.24	3.3	3.76	
Loss value per kg €	798,621	252,077	678,330	
Total value € at av. size 5.0 kg	3,993,105	1,260,385	3,391,650	8,645,140
Nominal cost of losses UK				
Total value of production (€ million)	467.6	420.7	462.4	
Losses (nos. of fish)	136,891	56,941	88,044	
Av. price/kg €	3.64	3.27	3.2	
Loss value per kg €	498,283	186,197	281,740	
Total value € at av. size 5.0 kg	2,491,415	930,985	1,408,704	4,831,104
Nominal cost of losses Ireland				
Total value of production (€ million)			65.4	
Losses (nos. of fish)			35,000	
Av. price/kg €			5.35	
Loss value per kg €			187,250	
Total value € at av. size 3.67 kg			687,208	687,208
Total all countries			Total	14,163,452

By far the most significant cause in terms of numbers of escape incidents was a hole in the net due to either biting (16%), predator damage (14%) or other causes. When the causes of holes in the net are examined (Fig. 3) it can be seen that taken together, net biting and predator damage, account for almost half (47%) of escape incidents due to a hole in the net.

The present study did not address the issue of negative environmental impacts associated with escapes from fin fish farms. There are a number of studies (Dimitriou et al., 2007; Jensen et al., 2010) which raise issues in this regard. Two key issues highlighted are the possibilities for genetic interactions (McGinnity et al., 2003) and the risk of competition with wild stocks.

The number of escapees recorded in northern Europe was much lower than in the Mediterranean. The total number of salmon and cod recorded as escaping during the study period was 1.27 million or less than 15% of the total number of escapees recorded. This may, as suggested by Jensen et al. (2010), in some measure be related to the more highly developed standards for equipment and structures including mooring arrays. It may also be due in part to the codes of good practice introduced by the industry themselves in these countries. One example is *The Code of Good Practice for Scottish Finfish Aquaculture* (http://www.thecodeofgoodpractice.co.uk/index.php) which has been in place since 2006. The Norwegian government has enacted legislation called NYTEK, first version mandatory from 2006, updated version mandatory from 2012, with some parts not mandatory until 2013 in which it specifies the technical standard NS9415, first edition in 2003 revised in 2009. This technical standard relates to cages, mooring systems and other components. Since the implementation of this legislation there has been a reduction in both the number of escape incidents and the numbers of fish escaping (Jensen et al., 2010). In Scotland, similar containment standards are presently under development and training programmes to improve husbandry staff understanding of containment management have been implemented (http://www.scotland.gov.uk/Topics/marine/Fish-Shellfish/18364/18692).

The role of holes in the net in a large number of escape incidents points towards the need to improve surveillance of net integrity, preventative maintenance programmes and testing and inspection of nets before deployment or redeployment. Where such programmes are widely employed numbers of escapes are significantly lower.

The study identified that the number one cause of escape incidents was due to net biting and the number one cause of large escape numbers was mooring failure. It was also concluded that there was a large variation in the level of awareness of the necessity of both training of staff and procedures or Standard Operating Procedures on containment related issues.

5. Conclusions

There were significant numbers of finfish escapes in all of the areas studied (8.9 million fish over the period of the study). The nominal cost of these escapes at point of first sale is very significant in terms of lost income (€47.5 million per annum). Implications of the escape incidents have been shown to have negative effects on the viability of individual commercial concerns. The public perception of the aquaculture industry has also been adversely affected by publicity surrounding high profile escape incidents.

Table 3
Nominal cost of losses to Spain, Greece and Malta.

	No. of sites per species from questionnaires	Escape incidents	No. of fish escaped over 3 years	Escapes per annum	2007 price/kg	Nominal cost (500 g)	No. of sites	% overall sites	Nominal cost of lost annual production	Total value of production (million €) 2007
Spain	24	15 Bream	5,849,000	1,949,666	€4.30	€4,191,781	111	21%	€19,960,861	95.5
	25	2 Bass	520,000	173,333	€4.98	€431,599	108	23%	€1,876,521	52.2
	3	1 Meagre	200,000	66,666			30	10%		
Greece[a]	6	15 Bream	909,200	303,066	€3.57	€540,972	210	2.8%	19,320,428	282
	5	9 Bass	65,100	21,700	€5.12	€55,552	130	3.8%	€1,461,894	245.7
Malta	3	22 Bream	87,900	29,300	€4.33	€63,434	4	75%	€84,579	4.8
	2	4 Bass	14,500	4833	€14.71	€35,546	3	67%	€53,053	1.1
								Total	€42,757,336	

Market size average for both bream and bass 500 g.
[a] 340 is the combined number of farms in 2006. (Source: Globefish 2007).

Two key drivers towards reducing escapes identified by the industry were standards for materials and site specific procedures and processes to ensure the use of appropriate equipment and its maintenance.

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