Estimating Illegal and Unreported Catches from Marine Ecosystems: Two Case Studies

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Abstract

Estimation of total harvests of marine organisms is essential if true impacts of fisheries are to be evaluated. Such estimates are difficult to obtain because, for many of the world's fisheries, an unknown proportion of the catch is not reported. Components of the unreported catch may include discards, deliberately misreported catch and unmandated catch (catch that it is not required to be reported). For many fisheries, estimates of misreporting or discarding exist, but may not apply to all periods of interest. Here we demonstrate a methodology for estimating unreported catches over time, based on knowledge of factors that influence misreporting in the fishery and on independent (published and unpublished) estimates of misreporting. Independent estimates and knowledge of influence factors are combined to assign quantitative estimates of misreporting to different periods so that time-series of misreporting can be obtained. The method is demonstrated for two national fisheries: Iceland and Morocco. The Icelandic analysis is a by-species approach for cod and haddock. The Moroccan analysis divides catches into demersal and pelagic categories, rather than individual species. Preliminary results suggest that Icelandic cod catches may have been underestimated by between 1% and 14% at different times, and haddock catches by between 1% and 28%. Underestimation of Moroccan catches appears to have been by as much as half in some cases. Uncertainty has been incorporated into our analyses by using multiple sources of information to provide upper and lower estimates of misreporting and by using a Monte Carlo simulation. These case studies show that it is possible to obtain some estimate of misreporting, even when rigorous data are lacking. Sources of information are presented so that areas where information is lacking are easily identified, offering a basis for comment, discussion and, it is hoped, collaboration that will lead to provision of further information and improvement of the estimates.

Introduction

Estimation of total harvests of marine organisms is essential if the true impacts of fisheries on marine ecosystems are to be evaluated. This is difficult because, for many of the world's fisheries, an unknown proportion of the total catch is not reported to any official body. In some cases, unreported catch may be deliberately concealed by individuals or organizations and in some cases there is no obligation to report (i.e., catches are unmandated). A number of methodologies have been used by researchers in an attempt to quantify unreported catches. For example, estimates of discarding are often obtained using some sort of observer program. Illegal landings are more difficult to quantify but may be estimated by comparison of reported landings with market sales, by interviews with fishers (e.g. Anon., 2001a; Gunnarsson 1995), or by tracing techniques (e.g. ISOFISH 1999). Estimates of bycatch and discarding for different fisheries have been obtained using models of the fishery (e.g. Stratoudakis *et al*, 1999; Ortiz *et al*., 2000; Medley 2001) and in some cases economic models have been used to estimate incentives to discard (Anderson 1994; Arnason 1994). A number of other methodologies are discussed in Alverson *et al.* (1994). It would be advantageous to make use of all the available specialist studies of unreported catches in a fishery and synthesize them into a single analysis. A proposal for such a methodology, based on adjustments to reported catch for a specified fishery, place and time, has been presented in a previous Sea Around Us project report (Pitcher and Watson 2000). Its workings are demonstrated in detail here with two preliminary case studies. Formal publication of the results will be presented elsewhere.

Estimation Method

We present a procedure to adjust reported catches, based on a spreadsheet, divided by decade (or other appropriate time-periods) and by category of misreported catch (discarded, illegal and unreported). Quantitative values are assigned to adjustment factors, based on reports and information explicitly attributed to a variety of sources, published and unpublished (e.g. from newspaper reports in some cases). All sources of information are clearly presented in such a way that areas where information is lacking can be easily identified, offering a basis for collaboration and discussion. Confidence intervals around estimates of total misreporting for each period in the analysis are obtained using a Monte Carlo simulation taking account of stated or estimated uncertainties. The procedure can be easily adapted as more species or fisheries are added to the analysis. Here, we demonstrate application of the method for two national fisheries: Iceland, where there are plentiful, reliable data on landings by species; and Morocco, where data are sparse.

Table 1. Summary of influences on the incentives to misreport catches from Icelandic waters from 1950 to 1999. Arrows indicate whether the influence is expected to increase or decrease incentive to discard/misreport.

Category	1950-1959	1960-1969	1970-1979	1980-1989	1990-2000
Mesh size	110 mm in codend enforced in 1954 (↓)	120 mm in codend enforced in 1963 (↓)	135 mm (1976) and 155 mm (1977) in codend enforced (↓)		
Fisheries control	EEZ to 4 miles in 1952 and 12 miles in 1958 (↓)		EEZ to 50 miles in 1972 and 200 miles in 1975 (↓), TAC introduced in 1976 (↑), Effort control on Icelandic boats in 1978 (↓), Real time areas closures to protect juveniles (1976) (↓)	ITQs for the main groundfish species in 1984 (↑), Small boats excluded and effort option on others until 1991 (↓)	Groundfish fishery changes to full ITQ system in 1990 (↑)
Other			Undersized fish confiscated (until 1984) (↑)	Undersized fish not in quota (1984-1987) (↓)	
New technology	Radar (↑), Sounders (↑), Nylon nets (↑)	Sonars (↑), Powerblock (↑)	Loran (↑)	Computerized jigging reels, Rockhoppers (↑), Headline and codend sensors (↓)	Computers (↑), GPS (↑), Sorting grids (↓)

Case Study 1: Iceland

Fisheries are central to Iceland's economy and have provided Icelanders with a high standard of living through much of the twentieth century. In general, Icelandic fisheries are believed to be well-managed, and, with ITQs, they are thought to have overcome many of the economic problems often associated with fisheries (Arnason 1995). Major fisheries exist for both pelagic and demersal species. The pelagic fishery (mainly capelin (*Mallotus villosus*), herring (*Clupea harengus*) and blue whiting (*Micromesistius poutassou*) provides the bulk of the catch, although the demersal fishery provides most of the revenue, generating approximately 75% of the total value of catches (Arnason 1995). Major demersal species are cod (*Gadus morhua*), haddock (*Melanogrammus aeglefinus*), saithe (*Pollachius virens*), redfish (*Sebastes* spp.) and Greenland halibut (*Reinhardtius hippoglossoides*). Today, most of the catch in Icelandic waters is taken by Icelandic vessels, although foreign fleets have fished in the region for several centuries. Foreign catches have been reduced considerably since 1950, when Iceland began to expand its exclusive economic zone (EEZ). For detailed descriptions of the history of Icelandic fisheries since the beginning of the last century, see Arnason (1995) and a *Sea Around Us* report by Valtýsson (2001).

Table 2. Incentives for Icelandic vessels to discard based on changes in management and technology given in Table 1. L= Low; M= Medium; N = N. *NOTES: Illegal catch refers to illegal landings rather than discards. Unmandated catch refers to fish legally eaten or taken home by fishers*. See also footnotes.

Fleet	Species	Type	50-54	55-59	60-64	65-69	70-74	75-79	80-84	85-89	90-94	95-00
Iceland	Atlantic Cod	Discards	L/M[a]	L/M[a]	L/M[a]	L[b]	L[c]	L/M[d]	L/M[d]	M[e]	M[e]	M[e]
		Illegal	N[f]	N[f]	N[f]	N[f]	N[f]	N[f]	N[f]	L[g]	L[g]	L[g]
		Unmandated	N[h]	N[h]	N[h]	N[h]	N[h]	N[h]	N[h]	N[h]	N[h]	N[h]
	Haddock	Discards	L/M[a]	L/M[a]	L/M[a]	L[b]	L[c]	L/M[d]	L/M[d]	M[e]	M[e]	M[e]
		Illegal	N[f]	N[f]	N[f]	N[f]	N[f]	N[f]	N[f]	L/M[i]	L/M[i]	L/M[i]
		Unmandated	L/M[j]	L/M[j]	L/M[j]	L/M[j]	L/M[j]	L/M[j]	L/M[j]	M[k]	M[k]	M[k]
Foreign	Atlantic Cod	Discards	L/M	L/M	L/M	L	L	L/M	L/M	M	M	M
		Illegal	N	N	N	N	N	N	N	L	L	L
	Haddock	Discards	L/M	L/M	L/M	L	L	L/M	L/M	M	M	M
		Illegal	N	N	N	N	N	N	N	L/M	L/M	L/M

a. EEZ to 4 miles introduced in 1952 and 12 miles in 1958, many areas closed to trawlers and Danish seiners. Introduction of radar, fish-finders and nylon nets. b. 120 mm cod end enforced. c. EEZ extended to 50 miles, reducing trawling. d. Undersized fish confiscated. EEZ extended to 200 miles. Effort control on Icelandic boats. Real-time area closures to protect juveniles. e. Introduction of ITQs in 1984. f. No ITQ system in place, mandatory to report all landings. g. Introduction of ITQs in 1984. h. Cod rarely eaten locally. i. Introduction of ITQs in 1984. Probable local black market for haddock. j. Fish legally taken home by fishers. k. Greater incentive to land more fish in this way after introduction of quotas.

Table 3. Estimates of discarding/misreporting of cod and haddock, by gear-type. Estimates are presented as percentages of reported catch of each gear-type (over and above reported catch) and refer to catches taken by Icelandic vessels. All figures are percentages. Sources are footnoted. *Note: Bottom Trawl includes lobster trawlers and shrimp trawlers*

Species	Gear	1980-1984	1985-1989	1990-1994	1995-1999
Cod	Handline		4[a]		2[b] - 22[b]
	Longline		4[a]		3[c] - 9[c]
	Danish Seine			2[b]	22[c] - 36[b]
	Gillnets		4[a]	1[d]	2[c] - 9[c]
	Bottom Trawl	6[d]	5[d] - 10[a]	0.4[d] - 4[c]	1[b] - 6[c]
Haddock	Longline		3[a]		3[c] - 14.7[e]
	Danish Seine			4[c] - 16[b]	2.3[e] - 22[c]
	Gillnets		3[a]		2[c] - 9[c]
	Bottom Trawl		0.8[e] - 8[a]	8[e] - 19.6[e]	5.2[e] - 22.3[e]
	General (*unmandated catch*)				12[f]

a. Gunnarsson (1995): Results of questionnaire returned by 591 fishermen: b. Pálsson (2001): Comparison of size composition from landings and those observed at sea; c. Anonymous (2001a): Results of Gallup International questionnaire returned by 1638 fishermen; d. Anonymous (1993): Comparison of landed catch of trawlers and catches observed at sea; e. Pálsson (2002) Comparison of length distributions measured at sea with landings; f. Anonymous (1999a; 1999b): Comparison of processing statistics and survey data (*see text*).

Discarding in Icelandic waters has been illegal since 1996. There is, however, little doubt that discarding still occurs, although its magnitude is widely debated. Other forms of misreporting are also believed to occur in some fisheries, but there is no official estimate of their magnitude. Changes to the management of Icelandic fisheries over the past fifty years have had varying effects on incentives to misreport. The following case study demonstrates our methodology for estimating unreported catches for two of Iceland's most important species, cod and haddock. A complete study of Icelandic fisheries would involve applying the methodology to all commercial species and include efforts to quantify total catches of non-commercial species for which official statistics do not appear. It should be noted that a major project has recently been initiated by the Icelandic government to compare catches by boats with observers with landings by boats without observers, in order to gain better estimates of the magnitude of discarding. Important changes to Iceland's regulatory regime are shown in Table 1.

Factors influencing discarding

Economic incentives to discard can occur whenever there are constraints on the amount of fish that can be officially landed. Constraints can be technological, where catching power exceeds onboard storage or processing facilities, or regulatory, where quotas restrict landings of certain species (Anderson 1994). In both cases, there is incentive for fishers to discard fish of lower value in order to fill the hold or quota with fish of the greatest value (this process is called high-grading; see Rettig (1986); Squires and Kirkley (1991); Anderson (1994); Walters and Pearse (1996); and Turner (1997) for discussion of the effects of quotas on discarding).

Technological advances that increase the likelihood of bumper catches are therefore likely to increase the incidence of discarding. There have been several major technological improvements in fishing power in Iceland during the past fifty years (see Table 1). For example, increases in horsepower and fish-finding and catching abilities have had a large impact on the size of hauls, especially of trawlers, and it would be very surprising if this did not lead to increased high-grading of catches. On the other hand, regulatory increases in mesh size since 1954, and the introduction of devices such as sorting grids on trawl nets have probably reduced bycatch and discarding. Another important factor influencing catches in Icelandic waters has been the introduction and dramatic increase in size of Iceland's exclusive economic zone (EEZ) since 1950, which has limited trawling in large areas around Iceland. Real time area closures used since 1976 have had similar effects. Each can last for up to 2 weeks if catch composition for a given area has high proportions of juvenile fish.

In 1976, the cod fishery was subjected to an overall catch quota, followed in 1977 by the introduc-

Table 4. Proportion of mean total catch of cod and haddock taken by five different demersal gear types. Proportions are rounded to two decimal places. *Note: Catches taken by other gear types (driftnets, seiners, mid-water trawlers and others) were each less than 0.5% of total catch and are not listed.*

Species	Gear	1980-1984	1985-1989	1990-1994	1995-1999
Cod	Handline	0.03	0.05	0.07	0.10
	Longline	0.09	0.10	0.17	0.20
	Danish Seine	0.01	0.03	0.03	0.07
	Gillnets	0.32	0.25	0.21	0.21
	Bottom Trawl	0.55	0.58	0.52	0.43
Haddock	Longline	0.12	0.13	0.16	0.19
	Danish Seine	0.00	0.03	0.05	0.09
	Gillnets	0.11	0.16	0.09	0.05
	Bottom Trawl	0.76	0.68	0.70	0.67

Source: ICES and Iceland National Data, provided by H. Valtýsson

Table 5. Estimates of discarding of cod and haddock by different gear-types, as a percentage of the total reported catch by all gear types. Estimates were obtained by multiplying the estimates in Table 2b with (unrounded) proportions in Table 2d. All figures are percentages. *Note: proportions shown in Table 2c were rounded for presentation: unrounded proportions were used to calculate the percentages in this table.*

Species	Gear	1980-1984	1985-1989	1990-1994	1995-1999
Cod	Handline		0.20		0.21 - 2.26
	Longline		0.39		0.59 - 1.76
	Danish Seine			0.06	1.48 - 2.42
	Gillnets		0.99	0.21	0.42 - 1.88
	Bottom Trawl	3.29	2.88 - 5.77	0.21 - 2.08	0.43 - 2.55
Haddock	Longline		0.38		0.58 - 2.82
	Danish Seine			0.21 - 0.82	0.20 - 1.94
	Gillnets		0.48		0.09 - 0.42
	Bottom Trawl		0.54 - 5.43	5.6 - 13.73	3.49 - 14.96

tion of individual effort restrictions for all demersal fisheries. In 1984, an individual quota system was applied to all demersal fisheries (but fishers could choose between this system and a restricted effort system until 1990: Arnason 1996). The introduction of quotas in the demersal fisheries is expected to have increased the incidence of high-grading of catches, especially in recent years, as quotas have been unexpectedly expensive.

It should be noted that not all operators of small boats work under the same quota system, even if they fish with the same gear, and therefore incentives to discard are not uniform within sectors of the fishing industry. For example, a recent Icelandic supreme court ruling stated that boats no longer require special fishing licences (of which limited numbers were available), and, as a consequence, there is now a growing number of operators who previously could not acquire fishing licences who now lease quotas for high prices. In order to be profitable, some operations such as this are inclined to retain only the most valuable fish. A rather sensational example of this occurred recently, when journalists participated on a trip on one of these boats and they reportedly discarded 20 tonnes of cod on a single two-day trip (Anon. 2001b). This type of misreporting is very difficult to quantify as it is often hard to verify the accuracy of such reports.

Other forms of unreported catch

Another side effect of the quota system is the deliberate misreporting of catches of valuable species that have low or expensive quotas. For example, since the introduction of ITQs, some vessels have been caught concealing catches of cod under layers of saithe, which has a lower value than cod, and then falsely reporting the whole catch as saithe. Since cod catches are so much higher than saithe catches, this type of misreporting is unlikely to have had a large effect on assessment of cod harvests. On the other hand, saithe catches may actually be overestimated.

A further source of error occurs with certain species that are consumed locally. According to Icelandic government processing statistics (Anon. 1999a), haddock, Atlantic halibut, common skate, and Greenland shark are the species for which the greatest proportion of total catch goes to domestic consumption. These species are commonly eaten by fishers at sea and a certain amount can also legally be taken home for their family. These amounts are unmandated, in that they are not required to be reported in any landing statistics. Comparison of estimates of local consumption of seafood obtained from official processing statistics (5,523 tonnes; Anon. 1999a) and estimates obtained by a survey of Icelanders' diets (12,352 tonnes; Anon. 1999b) reveal a discrepancy of 6,829 tonnes, implying that many more fish are landed than are reported. More than 70% of locally-consumed fish is haddock (Anon. 1999a), and the above figures would suggest that haddock landings are underestimated by almost 5,000 tonnes (equivalent to approximately 12% of the reported catch). Species which are mainly exported (such as cod) are monitored much more closely from place of landing through processing to final place of export (Halliday and Pinhorn, 1996) and the same types of errors are not expected to affect them.

There is also evidence of a black market for locally-consumed fish. Some fishers have been

Table 6. Interpolated percentage estimates of discarding by gear (*shaded cells/italics*). Estimates are presented as percentages of total reported catch (over and above reported catch) and refer to catches taken by Icelandic vessels.

Species	Gear	1980-1984	1985-1989	1990-1994	1995-1999
Cod	Handline		0.20	*0.20 - 2.26*	0.21 - 2.26
	Longline		0.39	*0.39 - 1.76*	0.59 - 1.76
	Danish Seine		*0.06 - 2.42*	0.06	1.48 - 2.42
	Gillnets		0.99	0.21	0.42 - 1.88
	Bottom Trawl	3.29	2.88 - 5.77	0.21 - 2.08	0.43 - 2.55
	TOTAL	3.29	4.52 - 9.77	1.07 - 6.37	3.13 - 10.87
Haddock	Longline		0.38	*0.38 - 2.82*	0.58 - 2.82
	Danish Seine		*0.21 - 1.94*	0.2 - 0.82	0.2 - 1.94
	Gillnets		0.48	*0.09 - 0.48*	0.09 - 0.42
	Bottom Trawl		0.54 - 5.43	5.6 - 13.73	3.49 - 14.96
	TOTAL		1.61 - 8.23	6.27 - 17.85	4.36 - 20.14

Table 7. Interpolation of estimates of misreporting of cod and haddock, from 1950 to 1999. Lower and Upper refer to the top and bottom of the estimated range of proportion of misreporting for each period.

Fleet	Species	Type	Limits	50-54	55-59	60-64	65-69	70-74	75-79	80-84	85-89	90-94	95-99
Iceland	Cod	Discards	Lower	0.02	0.02	0.02	0.01	0.01	0.02	0.02	0.0452	0.0107	0.0313
			Upper	0.06	0.06	0.06	0.03	0.03	0.06	0.06	0.0977	0.0637	0.1087
		Illegal	Lower	0	0	0	0	0	0	0	0.01	0.01	0.01
			Upper	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.03	0.03	0.03
		Unmandated	Lower	0	0	0	0	0	0	0	0	0	0
			Upper	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
	Haddock	Discards	Lower	0.02	0.02	0.02	0.01	0.01	0.02	0.02	0.0161	0.0627	0.0436
			Upper	0.06	0.06	0.06	0.03	0.03	0.06	0.06	0.0823	0.1785	0.2014
		Illegal	Lower	0	0	0	0	0	0	0	0.02	0.02	0.02
			Upper	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.06	0.06	0.06
		Unmandated	Lower	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.03	0.03
			Upper	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.12	0.12	0.12
Foreign	Cod	Discards	Lower	0.02	0.02	0.02	0.01	0.01	0.02	0.02	0.0452	0.0107	0.0313
			Upper	0.06	0.06	0.06	0.03	0.03	0.06	0.06	0.0977	0.0677	0.1087
		Illegal	Lower	0	0	0	0	0	0	0	0.01	0.01	0.01
			Upper	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.03	0.03	0.03
	Haddock	Discards	Lower	0.02	0.02	0.02	0.01	0.01	0.02	0.02	0.0161	0.0627	0.0436
			Upper	0.06	0.06	0.06	0.03	0.03	0.06	0.06	0.0823	0.1785	0.2014
		Illegal	Lower	0	0	0	0	0	0	0	0.02	0.02	0.02
			Upper	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.06	0.06	0.06

caught with far more fish than they or their families could have eaten themselves, and a particular fisher admitted that he had sold, on the black market, 200 tonnes of fillets in one year, equivalent to about 500 tonnes of live fish (Anon. 2000). Although the extent of this practice is not known, a recent poll found that 20% of 1,638 fishers interviewed have witnessed illegal landings of fish in Iceland and 76% believe that illegal landings occur (Anon. 2001a).

Estimating the effects of influence factors

Clearly, there are complex influences on incentives to misreport catches, some of which seem to have conflicting effects. Table 2 gives qualitative estimates of incentives to misreport for Icelandic fisheries between 1950 and 2000. These estimates are based on knowledge of the history of the fishery, as discussed above and listed in Table 1. In the absence of information about discarding by foreign vessels, incentives for foreign vessels to discard are considered to be the same as for Icelandic vessels. We acknowledge that this may be a poor assumption in some cases.

The magnitude of the influence factors (low, medium, high) is, at this stage, arbitrary. Factors are meant to give a relative indication of differences in the magnitude of misreporting among periods. To convert these qualitative estimates into meaningful figures, informed estimates are needed for at least some periods. There are several reports that could be used to guide conversion of influence factors into quantitative estimates for recent periods. Table 3 gives estimates of misreporting of cod and haddock by gear-type, according to six different studies. As in Pitcher and Watson (2000), we refer to these estimates as 'anchor points'. Percentages are of reported catch, and hence are over and above reported catch. To allow meaningful comparison of estimates-by-gear, proportion of mean total catch taken by each gear-type (Table 4) was used to rescale the estimates (Table 5).

Because the estimates were now proportional to the total catch taken by all gears, they could be added to gain estimates of total discarding by all gears as a percentage of the total reported catch. This was easily done for the period 1995-1999 because estimates were available for all types of gear. For the other periods, some blank cells needed to be filled. Table 2 shows that factors affecting discarding were relatively stable between 1985 and 2000 (according to our estimates).

Table 8. Mean reported landed catches of cod and haddock in Icelandic waters (tonnes). Please note that data for official foreign catches are only provided until 1997.

Fleet	Species	50-54	55-59	60-64	65-69	70-74	75-79	80-84	85-89	90-94	95-99
Icelandic	Cod	237541	284755	251557	232095	251103	311180	369110	361764	267408	210549
	Haddock	20143	26044	51199	39312	32490	39905	57376	50274	54180	+48953
Foreign	Cod	182815	202586	162513	144424	165175	39563	5692	2469	1343	583
	Haddock	34862	41295	52024	24607	11150	5385	2239	1283	1174	588

Source: ICES and Iceland National Data, provided by H. Valtýsson

Table 9. Estimates of missing catch (tonnes) for cod and haddock. Lower and Upper refer to top and bottom of the estimated range of misreporting for each period. Note that data for official foreign catches are provided only until 1997.

Fleet	Species	Type	limit	50-54	55-59	60-64	65-69	70-74	75-79	80-84	85-89	90-94	95-99
Iceland	Cod	Discards	Lower	4751	5695	5031	2321	2511	6224	7382	16352	2861	6590
			Upper	14252	17085	15093	6963	7533	18671	22147	35344	17034	22887
		Illegal	Lower	0	0	0	0	0	0	0	3618	2674	2105
			Upper	2375	2848	2516	2321	2511	3112	3691	10853	8022	6316
		Unmandated	Lower	0	0	0	0	0	0	0	0	0	0
			Upper	2375	2848	2516	2321	2511	3112	3691	3618	2674	2105
	Haddock	Discards	Lower	402.9	520.9	1024	393.1	324.9	798.1	1148	809.4	3397	2134
			Upper	1209	1563	3072	1179	974.7	2394	3443	4138	9671	9859
		Illegal	Lower	0	0	0	0	0	0	0	1005	1084	979.1
			Upper	201.4	260.4	512	393.1	324.9	399.1	573.8	3016	3251	2937
		Unmandated	Lower	402.9	520.9	1024	786.2	649.8	798.1	1148	1508	1625	1469
			Upper	1209	1563	3072	2359	1949	2394	3443	6033	6502	5874
Foreign	Cod	Discards	Lower	3656	4052	3250	1444	1652	791.3	113.8	111.6	14.37	18.26
			Upper	10969	12155	9751	4333	4955	2374	341.5	241.2	90.93	63.41
		Illegal	Lower	0	0	0	0	0	0	0	24.69	13.43	5.833
			Upper	1828	2026	1625	1444	1652	395.6	56.92	74.08	40.3	17.5
	Haddock	Discards	Lower	697.2	825.9	1040	246.1	111.5	107.7	44.77	20.66	73.62	25.62
			Upper	2092	2478	3121	738.2	334.5	323.1	134.3	105.6	209.6	118.4
		Illegal	Lower	0	0	0	0	0	0	0	25.67	23.48	11.75
			Upper	348.6	413	520.2	246.1	111.5	53.85	22.39	77	70.45	35.26

Blank cells were therefore filled in by interpolating literature estimates from the adjacent cells into blank cells for the periods since 1985 (Table 6: shaded cells).

The totals in Table 6 suggest that total discards for the period 1985 - 2000 were in the range of 1% - 11% of reported catch for cod and 2% to 20% of reported catch for haddock (over and above reported catch). While the estimates for cod appeared to be within the same general range for the three most recent periods, the upper estimates for haddock for the periods 1990-1994 and 1995 - 1999 were much higher than for the preceding period, 1985 - 1989 (Table 6). Incentives to misreport for both species were ranked as 'Medium' for the periods after 1985 (see Table 2). As there was fairly good agreement among the cod estimates for these periods, the cod estimates were used to set the percentage values for the category 'Medium'. The estimates for haddock, post-1990, were used to set the percentage values for the category 'Medium-High'.

Estimates of the amount of discarding (and other forms of misreporting) for periods prior to 1985 were obtained by extrapolating the ranges found in Table 6 back to previous periods, using the percentages in Table 6 as a guide. The following ranges were assigned:

Table 10. Estimated total extractions of cod and haddock obtained by adding reported landings (Table 2g) to estimated missing catch (Table 2h). Lower and Upper refer to the top and bottom of the estimated range of misreporting for each period. Unreported is percentage (rounded) of the total estimated catch not reported (over and above estimated total catch). Note that official data for foreign catches are only provided until 1997.

Fleet	Species	Limit	50 - 54	55 - 59	60 - 64	65 - 69	70 - 74	75 - 79	80 - 84	85 - 89	90 - 94	95 - 99
Iceland	Cod	Lower	242292	290451	256588	234416	253614	317403	376492	381733	272943	219244
		Upper	256544	307536	271682	243700	263659	336074	398638	411579	295138	241857
	% Unreported	Lower	2.0	2.0	2.0	1.0	1.0	2.0	2.0	5.2	2.0	4.0
		Upper	7.4	7.4	7.4	4.8	4.8	7.4	7.4	12.1	9.4	12.9
	Haddock	Lower	20949	27085	53247	40492	33464	41501	59671	53597	60286	53535
		Upper	22761	29429	57855	43243	35739	45093	64834	63461	73604	67624
	% Unreported	Lower	3.8	3.8	3.8	2.9	2.9	3.8	3.8	6.2	10.1	8.6
		Upper	11.5	11.5	11.5	9.1	9.1	11.5	11.5	20.8	26.4	27.6
Foreign	Cod	Lower	186471	206638	165763	145868	166827	40355	5806.2	2605.5	1371	607.43
		Upper	195612	216767	173888	150201	171782	42333	6090.9	2784.5	1474.4	664.24
	% Unreported	Lower	2.0	2.0	2.0	1.0	1.0	2.0	2.0	5.2	2.0	4.0
		Upper	6.5	6.5	6.5	3.8	3.8	6.5	6.5	11.3	8.9	12.2
	Haddock	Lower	35559	42121	53065	24853	11261	5492.5	2283.4	1329.7	1271.3	625.04
		Upper	37303	44186	55666	25591	11596	5761.7	2395.3	1466	1454.2	741.28
	% Unreported	Lower	2.0	2.0	2.0	1.0	1.0	2.0	2.0	3.5	7.6	6.0
		Upper	6.5	6.5	6.5	3.8	3.8	6.5	6.5	12.5	19.3	20.7

None	=	0 – 1%
Low	=	1 – 3%
Low/Med	=	2 – 6%
Med	=	3 – 12%
Med/High	=	4 – 24%
High	=	5 – 25%+

Percentages for categories for which there were no anchor points were determined by following the trend set by the anchor points (i.e., doubling the upper estimate and increasing the lower estimate by 1%). These ranges will be refined as more anchor points are added to the analysis. Note that the upper estimates vary more than the lower estimates, resulting in increased uncertainty as incentives to misreport increase. This also results in some overlap between categories, which we felt was realistic. Table 7 shows estimated ranges of misreporting based on Table 2 and the percentage ranges given above. There is, unfortunately, no quantitative anchor estimate for the magnitude of illegal landings. Table 9 gives estimates of missing catch, obtained by multiplying mean reported catch (Table 8) by interpolated estimates of misreported catch (Table 7). Table 10 then presents estimates of total fishery extractions for these species at Iceland from 1950 to 1998. The results are shown in Figure 1.

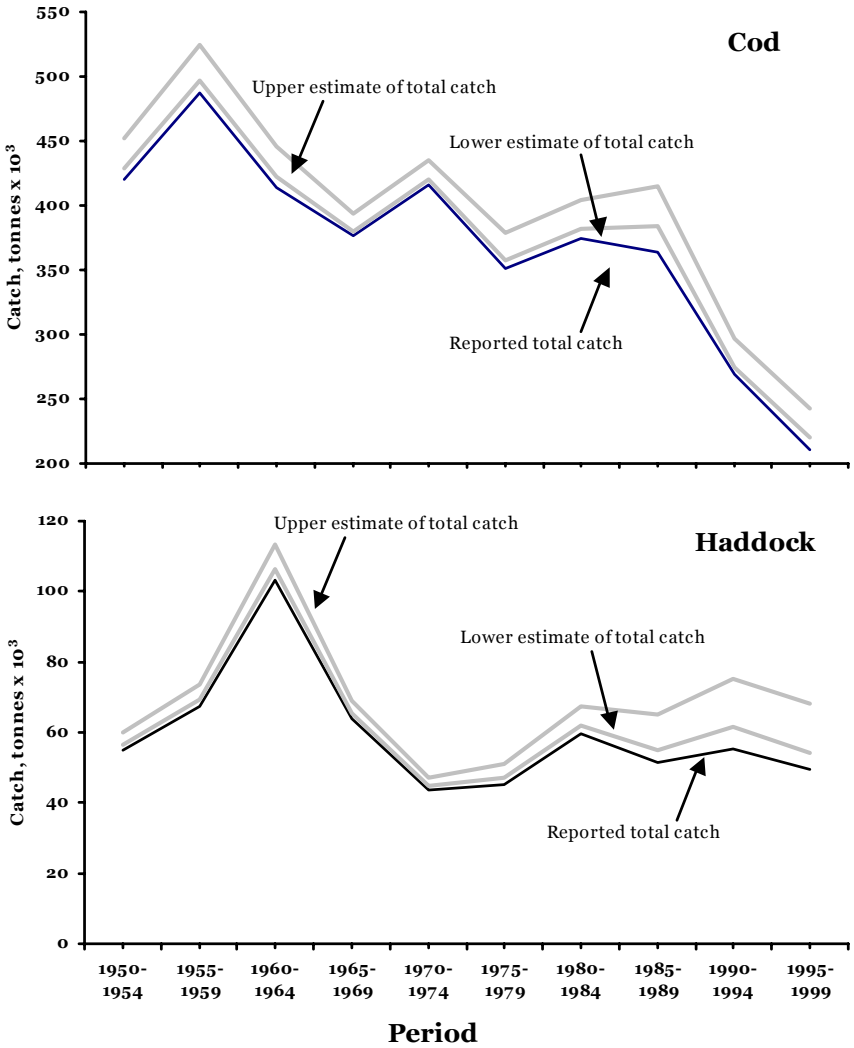

Figure 1. Estimates of unreported catch for cod and haddock in Icelandic waters. Note that catches include combined Icelandic and foreign catches. Note different scales for each species.

Monte Carlo simulations

The procedure above has illustrated how upper and lower estimates of total extractions may be estimated for individual species. Gaining an estimate of variability in missing catch for more than one species is more difficult, especially if ranges between upper and lower estimates are very different. Upper and lower estimates of total extractions may, however, be a desired outcome of the analysis. We have attempted to capture these ranges using Monte Carlo simulation.

For each species and fleet (i.e., Icelandic and foreign), in each period, a triangular distribution was assumed between the lower and upper estimates of total missing catch (shown in Table 9). Five thousand samples were taken from each triangular distribution. Each time a sample was taken, results for cod and haddock were summed, resulting in two datasets, Icelandic and foreign, for each period. A third dataset (both fleets combined) was generated by adding the elements of the previous two datasets. Upper and lower 95% confidence intervals and the mean were calculated for each dataset. It did not make sense for lower estimates of total extractions to be lower than the reported catch, so in cases where this occurred, lower 95% confidence intervals were truncated at the level of reported catch. Results are shown in Figure 2. The routine that was used is flexible, and can easily be modified to accommodate more species as they are added to the analysis.

Extending the method to other species

As for cod and haddock, the big-

gest influence on amounts of discarding for many species is thought to have been the introduction of the ITQ system. It has not always, however, led to increased discards as is often expected. Some species, such as long rough dab (*Hippoglossoides platessoides*) and starry ray (*Raja radiata*), have a long history of being discarded due to their low value. Since the implementation of the ITQ system, however, they have been retained in greater numbers (or even targeted) because they either do not have a TAC or their quotas are relatively inexpensive compared to high-valued species like cod and haddock. As suggested above, official saithe landings may actually be overestimates due to instances of cod hidden under layers of saithe in catches that were reported wholly as saithe. Other vessels have been suspected of reporting witch flounder as lemon sole , which if true, could cause errors in estimates of catch of both species.

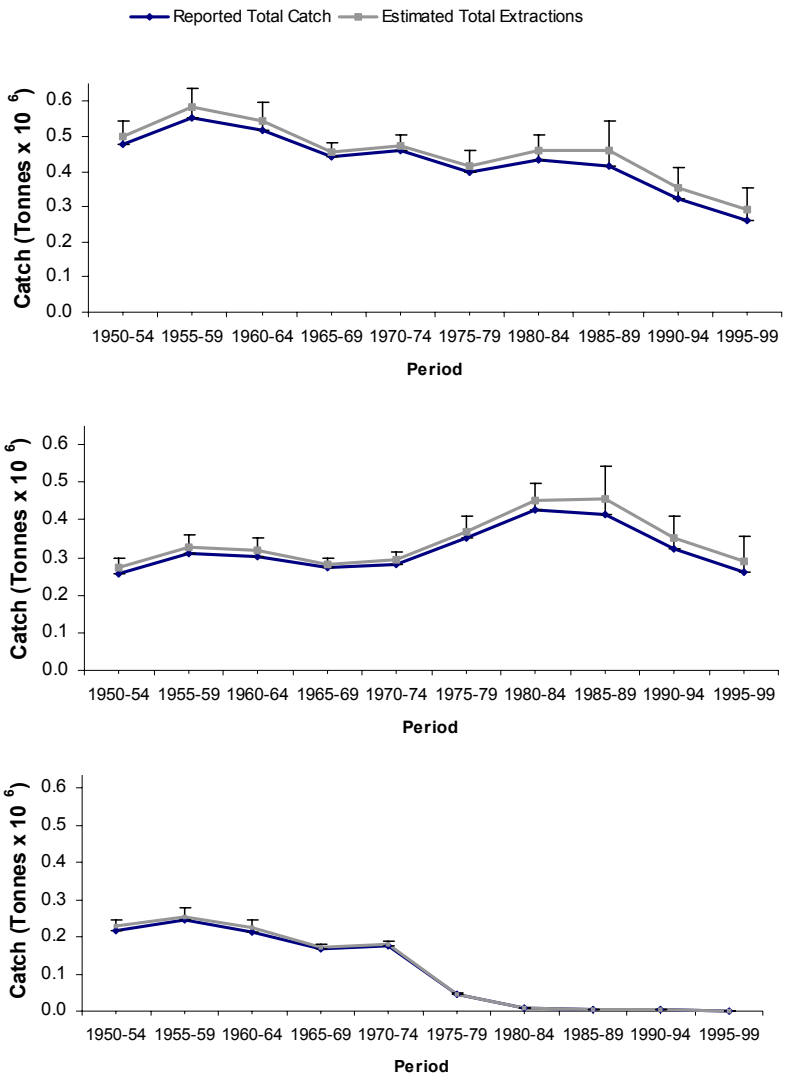

Figure 2. Estimated total extractions of cod and haddock from Icelandic waters, compared with reported catch, for a) Icelandic and foreign fleets; b) Icelandic fleet; and c) foreign fleet. The grey line shows the mean of 5,000 Monte Carlo samples (see text). Error bars represent upper and lower 95 per cent confidence intervals. Lower error bars are truncated at reported total catch.

Species living in deeper waters such as smoothhead (*Alepocephalus bairdii*), great silver smelt (*Argentins silus*), grenadiers *(Macrouridae*) and black scabbard fish (*Aphanopus carbo*) have been subjected to little fishing until relatively recently, and we can assume that discards and misreporting were low or non-existent for these species in the earlier years. When effort began to move to deeper waters in the 1960s (mainly to target Greenland halibut and redfishes), there were few or no reported landings for such species, which suggests that they were being discarded. This is confirmed by work by the French, who suggest that smoothhead discards may be 50% of the retained catch of targetted deep water fishes such as roundnose genadier *Coryphaenoides rupestris* (Lorance 1998; Lorance, pers. comm.). In recent years, however, more landings have been reported, implying that discarding of low-value deep water species may have decreased (Valtýsson 2001).

Sorting grids on prawn-trawl nets (introduced in 1996) have greatly reduced the incidence of by-catch of many species. While this is not expected to have had a great effect on the landing statistics of valuable species such as cod and halibut (which were always retained) it is certain to have reduced the amount of discarding of low-valued bycatch such as dab and starry ray and some of the deeper water species mentioned above.

Published estimates of discarding exist for some species other than cod and haddock (e.g. redfish: Gunnarsson 1995; and Agnarsson 2000; saithe: Gunnarsson 1995; and Anon. 1993) and for these species, the same procedure can be followed as for cod and haddock (above). For most species, however, there are no such estimates. In the absence of estimates anchored in the published literature (or other reliable sources), a detailed analysis of Iceland's fisheries would involve deciding which species can appropriately be grouped together, based on influences acting on

them, and extrapolating estimates of misreporting obtained from reliable sources for similar species. This is not the purpose of the present report, however, although it will be addressed in the future. In the mean time, it is hoped that the publication of this report will lead to comments, advice, the provision of more anchor points and ultimately, refinement of the estimates.

Table 11. Estimates of discarding and unreported landings for Moroccan coastal and industrial fleets and foreign fleets fishing in Moroccan waters. Percentages of discards are percentages of estimated total catch (including reported landings, unreported landings and discards) as used by Baddyr and Guénette (2001). Percentages of unreported landings are percentages of estimated total landings (including reported and unreported landings) as used by Baddyr and Guénette (2001). Sources are footnoted.

Fleet	Fishery	Type	1970-1979	1980-1989	1990-1999
Coastal Morocco	pelagic	discards			0% - 4% [1]
	demersal	discards			5%[4] - 13%[1]
	all	unreported		23%[2]	47% [1] - 60%[3]
Industrial Morocco	pelagic	discards			0%[5]
	demersal	discards	66% [4]	46% [4]	30% [5]
	all	unreported			47% [1] - 60%[3]

1. El Mamoun (1999); 2. El Hannach *et al.* (1986); 3. Durand (1995); 4. Balguerias (1997); 5. Haddad (1994)

Case study 2: Morocco

It is not always possible to estimate unreported catches in as much detail as shown above. Icelandic law requires that landings of almost all species are reported and very detailed catch statistics are available for all types of fishing gear. Many other countries, particularly in low latitudes where mixed species fisheries are common, do not collect such detailed statistics. The following example illustrates an application of our methodology to a more data-poor fishery. This fishery has already been presented in detail in another report (Baddyr and Guénette 2001) and will only be briefly discussed here.

Moroccan fisheries can be classified under three headings: the Moroccan small-scale fleet, consisting mainly of small wooden dories; the more modern coastal fleet, which consists of medium-sized trawlers, purse seiners and long-liners; and the industrial fleet, which is almost exclusively made up of large freezer trawlers fishing for several weeks at a time. Foreign vessels, mainly from Spain, Eastern Europe, Japan and Korea have also fished extensively in Moroccan waters (see Baddyr and Guénette 2001). The number of vessels in the small-scale fleet is difficult to assess and the catch is largely unknown. Baddyr and Guénette (2001) have estimated the catch for this fishery. Baddyr (1989) concluded that discarding does not occur in the small-scale fishery, as the whole catch is sold. Estimates of unreported landings and discarding are therefore presented only for coastal, industrial and foreign fleets. Unreported landings include consumption by fishers (similar to the unmandated landings in Iceland), illegal sale of fish and weighing mistakes.

Table 11 shows estimates of discarding and underreporting obtained from several sources. These estimates were used as anchor points and interpolated into periods for which there was no information about misreporting (Table 12). Assumptions used to make the interpolations are footnoted and were discussed in Baddyr and Guénette (2001). Recall that in the Iceland example, anchor points were used to guide assignment of ranges which corresponded to different categories in the table of influences (Table 2). In this case, a slightly different approach has been adopted when fewer time periods are under consideration. Here anchor estimates were interpolated directly into blank cells if the influences were considered to be the same. For some periods, where there were two published estimates of misreporting, a possible range in the amount of misreporting was obtained (an 'anchor range'). Where there was no anchor range, interpo-

Table 12. Interpolation (shading/italics) of percentage estimates of misreporting for Moroccan fisheries from 1970 to 1999. Reasons for interpolations are footnoted. All estimates for which there was no 'anchor range' were assumed to be accurate to within ±5% (see text for discussion).

Fleet	Fishery	Type	1970-1979	1980-1989	1990-1999
Coastal	pelagic	discards	*0 - 4 [a]*	*0 - 4 [a]*	0 - 4
Morocco	demersal	discards	*30 [b]±5*	*20 [c]±5*	5 - 13
	all	unreported	*23 [d]±5*	23±5	47 - 60
Industrial	pelagic	discards	No indust. fleet	*0 [e]+5*	0+5
Morocco	demersal	discards	66±5	46±5	30±5
	all	unreported	*47 - 60 [f]*	*47 - 60 [f]*	47 - 60
Foreign	pelagic	discards	*0 [e]+5*	*0 [e]+5*	*0 [e]+5*
	demersal	discards	*66 [g]±5*	*46 [g]±5*	*30 [g]±5*
	all	unreported	*23 - 47 [h]*	*23 - 47 [h]*	*23 - 47 [h]*

a. Discarding was never very high and is probably decreasing with the use of freezer boats; b. Assumed to follow the same trend as the industrial fleet (see below); c. Assumed to follow the same trend as the industrial fleet (see below); d. Assumed equal same as the 1980s because same economic context for market for fish in Morocco; e. Assumed to be the same as for the 1990s; f. Assumed higher than for coastal fleet because there were landings outside the country (Canaries); g. Assumed the same as for the industrial fleet because most observer information used for the industrial demersal fleet comes from foreign vessels; h. Assumed intermediate between coastal and industrial fleet. Although context is different, the incentives to cheat and opportunities to sell the fish are as high as for Moroccan boats.

Table 13. Estimates of total extractions (tonnes) of marine organisms from the Moroccan fishery for the period 1970-1999. Lower and Upper refer to the top and bottom of the estimated range of misreporting for each period.

			1970-1979		1980-1989		1990-1999	
Fleet	Fishery	Type	Lower	Upper	Lower	Upper	Lower	Upper
Coastal	Pelagic	Reported landings	228924	228924	307267	307267	440044	440044
Moroccan		Unreported landings	50252	89026	67449	119493	390227	660066
		Discards	0	13248	0	17782	0	45838
		% Unreported	*18*	*28*	*18*	*28*	*47*	*60*
		% Discards	*0*	*4*	*0*	*4*	*0*	*4*
		Total Estimated Extractions	279175	331198	374715	444541	830271	1145947
	Demersal	Reported landings	22615	22615	78913	78913	62900	62900
		Unreported landings	4964	8795	17322	30688	55779	94350
		Discards	9193	16913	16983	36534	6246	23497
		% Unreported	*18*	*28*	*18*	*28*	*47*	*60*
		% Discards	*25*	*35*	*15*	*25*	*5*	*13*
		Total Estimated Extractions	36773	48323	113217	146134	124926	180747
Industrial	Pelagic	Reported landings			26394	26394	29294	29294
Moroccan		Unreported landings			23406	39591	25978	43942
		Discards	No industrial		0	3473	0	3855
		% Unreported	pelagic fleet		*47*	*60*	*47*	*60*
		% Discards			*0*	*5*	*0*	*5*
		Total Estimated Extractions			49800	69458	55272	77090
	Demersal	Reported landings	5998	5998	63460	63460	96771	96771
		Unreported landings	5319	8996	56276	95190	85816	145156
		Discards	17700	36709	83206	165126	60862	130268
		% Unreported	*47*	*60*	*47*	*60*	*47*	*60*
		% Discards	*61*	*71*	*41*	*51*	*25*	*35*
		Total Estimated Extractions	29016	51703	202942	323776	243449	372196
Foreign	Pelagic	Reported landings	850871	850871	832512	832512	724680	724680
		Unreported landings	254156	754546	248672	738265	216463	642641
		Discards	0	84496	0	82673	0	71964
		% Unreported	*23*	*47*	*23*	*47*	*23*	*47*
		% Discards	*0*	*5*	*0*	*5*	*0*	*5*
		Total Estimated Extractions	1105027	1689912	1081185	1653450	941143	1439286
	Demersal	Reported landings	431211	431211	238261	238261	146746	146746
		Unreported landings	128803	382395	71169	211288	43833	130133
		Discards	875920	1991931	215028	467898	63526	149089
		% Unreported	*23*	*47*	*23*	*47*	*23*	*47*
		% Discards	*61*	*71*	*41*	*51*	*25*	*35*
Total Estimated Fishery Extractions			1435934	2805536	524458	917448	254105	425967

lated estimates were given an upper and lower bound of ±5% (Table 12). Although this was somewhat arbitrary, we feel this was not an inappropriate figure. Anchor ranges, where obtained, ranged from 4% to 13% in any particular period (see Table 11) and our upper and lower bounds of ±5% are within this region. Estimates of unreported catch, discards and total extractions are shown in Table 13. Estimates of the range of total misreporting for each period were obtained using a similar Monte Carlo simulation as described above. Results are shown in Figure 3.

So far, this analysis has not attempted to identify the composition of the unreported catch. Indeed, for many of the world's fisheries, including Morocco, records of exact compositions of landings do not exist. For example, reported landings of demersal species in Morocco were dominated by an unidentified mixture of species and a large part of the foreign catches were unidentified (Baddyr and Guénette 2001). When the composition of the reported catch is not even known, it is probably not possible to quantify the magnitude of misreporting for individual species. It is possible, however, to at least identify some of the species that make up the unreported catch. These are briefly discussed below.

Discarding

Sardines comprised the majority of the pelagic catch and also the majority of discards (approximately 94% of the total catch: Oueld Taleb 1988). These are discarded either at sea if they are damaged in the nets or during net cleaning (El Mamoun 1999). As discarding by pelagic fleets is considered to be less than 5% of the total catch (Table 12, 13), the quantity of discards of other pelagic species is probably not significant (less than 0.3% of the total catch). In demersal fleets,

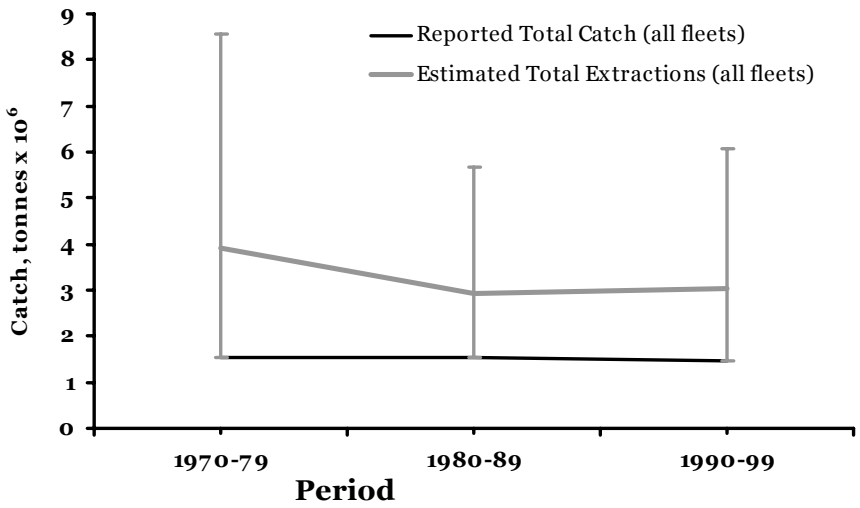

Figure 3. Estimates of total extractions of all species from Moroccan waters, compared with reported total catch, for all fleets combined. The grey line shows the mean of 5,000 Monte Carlo samples. Error bars represent upper and lower 95% confidence intervals. Lower error bars are truncated at the reported total catch .

coastal bottom trawlers (which landed more than 90% of the Moroccan commercial catch) discarded undersized and putrefied commercial species (cephalopods and a number of species in the families Trichiuridae, Sparidae, Merluccidae, Pleuronectiformes, Scianenidae, Haemulidae and Gadidae). A range of other species were also discarded, including boarfishes (*Macrorhamphorus scolopax* and *M. gracilis*), small-spotted cat sharks (*Scyliorhinus canicula*), sabre argenté (*Lepidopus caudatus),* conger eels (*Conger conger*), crabs, rays and rockfishes (El Mamoun 1999).

The composition of species discarded by Spanish cephalopod trawlers consisted mainly of seabream, other unidentified demersal finfish and members of the families Chondricthyes and Triglidae and invertebrates other than cephalopods (Balguerías 1997). It is probably appropriate to assume a similar composition for other types of demersal trawlers and also for Moroccan industrial demersal vessels.

Underreporting

Durand (1995) reported that up to 60% of Moroccan catch may be processed through illegal channels to avoid taxes. This particularly applies to mackerel and anchovies and other valuable commercial species. Cephalopods and crustaceans are also very susceptible to underreporting (El Mamoun 1999). In the 1970s and 1980s, a large proportion of the Moroccan industrial fleet's catch was landed outside Morocco (e.g. in the Canaries) and we can assume that the composition of species unaccounted for in this period is similar to the composition of today's commercial catch.

These very broad groups of species can be used as a starting point for a more complete analysis of species for which catches are underestimated or unknown.

Knowledge of Morocco's marine ecosystems and the demography of its different species will assist in determining which species are most likely to be caught in which fisheries. Examination of markets and prices for different species should indicate which species are more likely to be discarded and for which species there is likely to be a black market. As with all analyses of this type, it is most important to maintain contact with individuals who have detailed knowledge of the fishery, who can provide information to fill in gaps where data are missing.

Discussion

The results obtained for Icelandic cod and haddock must be considered as preliminary, as more information is needed for periods prior to 1985. More information is also needed about factors influencing foreign fleets, which were assumed to have been under the same influences as Icelandic fleets. For example, it is of interest that when the foreign trawlers began operating in Icelandic waters in the end of the 19th century, they quickly became notorious for only retaining flatfishes and haddock but discarding large amounts of cod (Thor 1992).

The most problematic and subjective part of the analysis was assigning percentage values to the influence factors. In analyses such as these, there will inevitably be occasions when estimated influence factors do not seem to agree with the anchor points, as was the case for haddock for the periods 1990-1994 and 1995-1999. In this case, because the anchor points were considered to be reliable, we chose to recognise this as a real trend and upgraded our estimate of the influence factors for this period. In other cases, the source of these anchor point may be considered less reliable than the table of influences. For the present, problems such as this need to be treated on a case-by-case basis, until there have been enough

case-studies to develop a more formal framework for dealing with them. More information is needed about influences acting upon other species, including susceptibility to different gears and economic factors such as cost of quotas and market value.

The Moroccan case study illustrated that it is possible to obtain estimates of underreporting, even when quantitative data are lacking, and that in some cases, underreporting may be significant. Coarse estimates of species compositions of unreported catches were obtained and it is hoped that these estimates will be refined as more information comes to hand. The advantage of the methodology is that it allows the available information to be laid out, such that gaps in our knowledge and areas that need to be addressed can be clearly identified. So far, most of the information used to anchor estimates has come from published reports, newspapers or university theses, although there is no reason that personal comments or other sources deemed reliable could not be used. Ideally, there should be at least one independent estimate of misreporting for each category of unreported catch. The final estimate obviously improves as more independent estimates are included.

Uncertainty is an intrinsic part of the issue of misreporting, especially when catches are illegal and information is sparse. Uncertainty has been incorporated into our analyses by using multiple sources of information to provide upper and lower estimates of misreporting. Where this was not possible, as in the Moroccan case, we have chosen a degree of uncertainty of ±5%, which we did not consider unreasonable. Estimates of uncertainty were extended to multiple species and fisheries using a simple Monte Carlo simulation, which captured upper and lower bounds of total estimated misreporting, within the limits obtained for individual species and fisheries. As more information comes to hand, we expect to be able to reduce the amount of uncertainty associated with the analysis by adding more anchor points. In many cases, however, there will always be limited information available.

In these two case-studies, we considered all sources of information to be equally reliable (i.e., we did not weight estimates according to our opinion of the reliability of the source). This was because the estimates, in this case, all came from scientific papers, scientific reports, theses or large-scale surveys, with one exception, Pálsson (2001), which was a newspaper article. Newspaper articles would normally be treated with some suspicion in terms of reliability. In this case, however, the author was an Icelandic fisheries scientist, with numerous scientific publications. In future work, it may be necessary to use newspaper reports or personal comments as anchor points and the reliability of these will have to be decided on a case-by-case basis.

Despite inherent uncertainties associated with this methodology, we reinforce Pitcher and Watson's (2000) assertion that it is unacceptable to settle for a zero adjustment of unreported landings just because they are difficult to quantify, or because of political pressure to do so. The results presented in this report should be considered as preliminary and are presented in the hope that they will generate comments and discussion of the methodology and the estimates.

Acknowledgements
We would like to thank Olafur K. Pálsson, Marine Research Institute, Iceland for helpful comments.

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