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Etymology of Ghoti

George Bernard Shaw (1856–1950), polymath, playwright, Nobel prize winner, and the most prolific letter writer in history, was an advocate of English spelling reform. He was reportedly fond of pointing out its absurdities by proving that 'fish' could be spelt 'ghoti'. That is: 'gh' as in 'rough', 'o' as in 'women' and 'ti' as in palatial.

Estimating illegal and unreported catches from marine ecosystems: a basis for change

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Abstract

To evaluate the impacts of fishing on marine ecosystems, the total extraction of fish must be known. Putting a figure on total extraction entails the difficult task of estimating, in addition to reported landings, discards, illegal and unmandated catches. Unreported catches cast various types of shadow, which may be tracked and estimated quantitatively. Some shadows of unreported catches are reviewed, for example, an innovative, well-funded NGO publicizes illegal catch in the Southern Ocean. For various reasons, official figures often have the implicit but unacceptable assumption that such categories are null. We present an estimation procedure based on adjustment factors taken from observer reports, correspondents and published information that track changes in a regulatory regime, and hence reflect incentives and disincentives to misreport. Monte Carlo simulations address uncertainty using multiple sources of information to provide upper and lower estimates. Once in place, this method provides preliminary estimates that may be refined without disruption. The method is demonstrated for fisheries in Iceland and Morocco. We use a 'by-species' approach for Icelandic cod and haddock, while the Moroccan catch is divided into demersal and pelagic categories. Results suggest that Icelandic cod catches may have been underestimated by between 1 and 14% at different times, and haddock by between 1 and 28%. Underestimation of Moroccan catches appears to have been as much as by 50%. These case studies show that it is possible to obtain estimates of misreporting, even when direct data are lacking. Our method encourages transparency because sources of information are presented so that uncertain values are easily identified, offering a

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Received 21 Mar 2000 Accepted 9 Jul 2002 basis for comment, collaboration and refinement in estimating illegal and unreported fishing.

Keywords discards, Iceland, illegal and unreported fishing, Morocco

"Shame to him that speaks not forth:

for never was the time so good as now" Robert le Coq, Bishop of Laon, 1356, denouncing the anarchy that prevailed under misrule by the Dauphin of France (Fig. 1)

Introduction

Estimation of the total extractions of marine organisms is essential if the true impacts of fisheries are to be evaluated. Ecosystem analysis techniques suitable for this on a global scale have only recently become available (e.g. in the 'Sea Around Us' project: see articles in Pauly and Pitcher 2000). Unfortunately, estimation of total catch is not easy because, for many of the world's fisheries, an unknown amount is not reported to any official body. In some cases, unreported catch may be deliberately concealed by individuals or organizations, and in other cases, for certain species, there is no obligation to report catches. In this paper, we present a methodology for making estimates of unreported catch. Our analyses will touch on controversial topics, and can be expected, in some cases, to be at variance with conventional assessments or official positions.

Categories of fisheries catches

Fisheries catches may be separated into three components:

- 1 Nominal catch reported to a monitoring agency: generally to a national body that itself reports to FAO (Food and Agriculture Organization of the United Nations).
- **2** *Reported discards*: the nontargeted part of a catch, thrown overboard and often consisting of the juveniles of targeted or other species caught due to the unselective nature of the gear. At least in recent years, there are generally attempts to estimate this by an observer program.
- 3 Unreported catch: consisting of categories not covered by the reporting system in question. Category 3, unreported catch, may be further subdivided into

- **3.1** *Unreported discards*: which may or may not be illegal, but are not reported by observers.
- **3.2** Unmandated catches: catches that a given agency is not mandated to record, either on account of the small size of the vessel (e.g. catch is not reported from small inshore vessels in the UK), or the nature of the species (e.g. lumpfish, *Cyclopterus lumpus*, in Iceland). It may include discards of species not considered important enough to record, such as pelagic species in some groundfish fisheries. A further example is catch from sport fisheries, which is often unmandated (it is not included in the FAO database) but can be significant (see Walters 1995).
- **3.3** *Illegal catch*: catches that contravene a regulation from the regulatory body. They may be unreported because there is no legal right to fish in the area (poaching), or may be landed away from the home port or trans-shipped to foreign-flagged vessels at sea. It includes disreported catches, whose identity (by species or size) may be deliberately misreported and concealed, usually to conceal quota violations, such as haddock (*Melanogrammus aegelfinus*), reported as cod (*Gadus morhua*), salmon (*Salmo salar*) concealed under surface layers of hake (*Merluccius merluccius*), or cod reported as 'blackfish'.

As well as unreported and illegal catches, the total mortality experienced by a stock also includes ghost ('cryptic') fishing mortality and other unaccounted sources of mortality. This topic is comprehensively reviewed by Alverson (2000), building on the work of ICES (1995), and is not considered in detail here.

While our work was in progress (Pitcher and Watson 2000) and following a series of discussions in international fora such as the International Maritime Organization (IMO), the Fisheries and Agriculture Organization of the United Nations (FAO) convened a working group with mandate to evaluate, 'illegal, unreported and unregulated'catch (IUU: Bray 2000), whose three categories are as follows (Bray 2000):

Figure 1 A contemporary illustration of Robert le Coq, Bishop of Laon (northern France), said to be possessed of a 'dangerous eloquence', stating his case in 1356 for immediate action to remedy the chaos in northern France to officers of the French king, Jean II, then voluntarily imprisoned, in some comfort, in London. Robert's merchant friend Etienne Marcel, Mayor of Paris, who also led the revolt, was murdered in 1358, but despite having to flee France when Jean II died in exile and the former Dauphin, Charles V ('Charles the Wise' - he built both the Bastille and the Louvre) became king in 1364, the wiley Robert died of natural causes as Bishop of Aragon in 1373. Lauded by English speaking historians like Barbara Tuchman as being from humble origins and one of the first commoners known to have possessed his own library, French historians tend to regard Robert le Coq as an English spy. Image from 'Grandes Chroniques de France', fol. 402v (70 mm \times 65 mm) France, Paris, 14th Century. Permission for use of image given by Bibliothèque Nationale de France.



1 Illegal Fishing

- **1.1** Poaching: Fishing within coastal states' jurisdictions by vessels with no permission to fish there.
- **1.2** Illegal fishing also occurs when parties fail to comply with the conservation and management measures of the regional fisheries bodies.
- **1.3** Illegal fishing can also occur on the high seas when fishing is contrary to articles 116–119 of

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United Nations Convention on the Law of the Sea (UNCLOS).

- **2** *Unreported Fishing*: Unreported, misreported and under-reported fishing.
- **3** *Unregulated Fishing*: Vessels allowed to operate outside management controls or where there are no reporting requirements or where there is lack of detailed knowledge of an area's fishery resources.

The three FAO categories map easily into the operational categories we use in our algorithm. FAO's

illegal catch actually includes an element that may be reported (1–2 above), an estimated element (e.g. observer estimates of discards) and an unreported component. The FAO 'unregulated catch' category overlaps largely with our 'unmandated' category. The term 'unauthorized' fishing is also used, but also does not easily link to the other categories, except as an overarching term for all unreported and misreported catches.

An assumption of zero is unacceptable

Where landing or catch data do not provide amounts of discards, or estimate unreported catches, it is important to realize that an implicit assumption has often been made that such categories are zero. It is not our purpose to comment on the effect that such assumptions may have on conventional stock assessments and, in fact, estimates of some unreported catches, sometimes called 'unassigned', are often used in stock assessments. Presumably for fear of embarrassing state governments, these figures generally remain confidential, or lie concealed in semiprivate stock assessment working papers. In any event, they are not attributed to nations or locations but only to the fish stocks under examination. Even FAO's own, well-founded study of discards (Alverson et al. 1994) is omitted from the published FAO database since this is mandated to report only landings. Leaving figures at an implicit zero, as databases in the public domain tend to do, is unacceptable (Pauly 1998), and any percentage estimate of unreported catch by category, based on validated information, will likely be closer to the truth.

A review of estimates of unreported catches

A number of methodologies have been used by researchers in an attempt to quantify unreported catches. For example, illegal landings have been estimated by comparison of reported landings with fishmeal factory outputs. In the late 1980s, official landing figures for the Ecuadorian tropical chub mackerel (*Scomber japonicus*) fishery were suspect and a logbook system had proved unreliable. Since catches and catch-per-unit-effort for this economically important fishery had been declining markedly, an accurate assessment of the fishery using reliable catch data was urgent (Patterson *et al.* 1990; Pitcher and Stokes 1990), and indeed the stock collapsed soon afterwards (Patterson *et al.* 1993). The catch was cleverly estimated from the numbers of sacks of fishmeal output from the fishmeal factories (Patterson *et al.* 1990). The weight of fish input to the fishmeal process was back-calculated from conversion ratios at each stage of the industrial process. The number of fishing vessels in each month was estimated from official permits issued each day ('zarpes'). Knowledge of the fleet structure allowed an estimate of the catch which did not go through this route (approximately 15%). Not only were the final catch estimates about double the official catch statistics, but, disconcertingly, there was poor correlation between the two sets of figures.

True catches of Peruvian anchovy (*Engraulis ring-ens*) in the 1970s were similarly estimated after it was realized that fish meal plants were operating well below the stated conversion efficiency (Castillo and Mendo 1987). Adjustments made after structured interviews with industry members resulted in estimates of catch much closer to the capacity of processing plants and with fishmeal exports. For example, the official 1970 catch figure of 12 million tonnes was revised upward to 16 million tonnes.

In Lake Malawi, artisanal catches of usipa (*Engraulicypris sardella*), caught at night and hence outside the work time of beach observers, were estimated by a census of sacks of dried fish (Lewis and Tweddle 1990). Exports from the Nankumba peninsula, which represents only 5% of the lake shoreline, represented a catch five times greater than the official catch for the whole lake. The true usipa catch in 1985/1986 was likely between 50 000 and 100 000 tonnes, contrasting with the official figure of 5573 tonnes. In South Africa, net confiscations, and questionnaires filled in by local fishers after gaining the confidence of local tribal chiefs (Mann 1995), showed that true catches were 142–210% of the reported catch.

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) and in some cases economic models have been used to estimate incentives to discard (Anderson 1994; Arnason 1994). Patterson (1998) tracked the numerical 'shadows' of illegal catch using a VPA technique with three gadoid fisheries, North Sea cod and west Scotland cod and whiting. He concluded that West Scotland stocks, but not those in the North Sea, had been under-reported since 1991 by a factor of 30-60%. In the French deep-water trawl fishery on the mid-Atlantic ridge, discards of smoothhead, Alepocephalus bairdi, a large watery fish of no commercial value, were equal to approximately 50% of the retained catch of grenadiers, roughy, scabbard fish

and deep-water sharks (P. Lorence, Personnel Communication), an example of unmandated discards.

In 1997, it is estimated from surveys that more than 75% of swordfish (*Xiphius gladius*) marketed in Spain was illegal. ICCAT records show that Spain exceeded its catch limit in both the North and South Atlantic in every year from 1996 when the ICCAT quotas were introduced. For bluefin tuna (*Thunnus thynnus*), Spain exceeded the catch limits of about 8000 tonnes by 19% in 1995, 58% in 1996 and 51% in 1997. Moreover, France, Italy, Japan and Morocco are reported as having illegal catches for bluefin tuna and swordfish as large as those of Spain (Raymakers and Lynham 1999).

The 1996-1997 annual quota for Patagonian toothfish (Dissostichus eleginoides), served as 'Chilean Sea Bass' in seafood restaurants world-wide, was set at 17 000 tonnes by Commission for the Conservation of Antarctic Living Marine Resources (CCAMLR). Tracing and surveillance techniques have been used to estimate illegal catches of toothfish and southern bluefin tuna (Thunnus maccoyii) (ICCAT 2000). Illegal catches taken around Heard and McDonald Island (Australia), Kerguelen Island (France) and Prince Edwards and Marion Island (South Africa) appear to have exceeded the legal quota by a factor of 500%. These illegal catches and sales of toothfish have been traced by an NGO. International Southern Oceans Longline Fisheries Information Clearing House (ISOFISH), based in Tasmania, and funded by the Australian government and the fishing industry (ISOFISH 1999). Publicity by ISOFISH led to pressure on vessel owners by Argentinean, Spanish and Chilean governments. Some vessels were later reflagged in Belize, Panama, and Honduras. Moreover, port and trade authorities in Uruguay, Mauritius, Mozambique, Namibia and the French island of Réunion were identified as 'providing unquestioning support' to the toothfish poachers, in allowing transshipments of illegally caught fish. As consequence of this publicity, toothfish conservation is now of international concern. ISOFISH is a model of what may achieved, with adequate funding, in identifying specific illegal fishing and tracking the trade in illegally caught fish that drives such activities.

Harris (1998), who appears to have had access to a considerable amount of privileged information, reports many instances of discards and disreported catch on Canadian fish stocks that could be used to provide preliminary figures for Canadian waters and that could be adjusted later in the light of better information. Some examples are:

- In Canada, the arrest of a Spanish trawler (the *Estai*) in 1995, revealed a specially constructed secret hold that concealed unreported, illegal and undersized catch. There were two sets of logbooks, each reporting different catch figures. From the skipper's secret logbook, total catch was found to be 100% under-reported (Harris 1998). Moreover, 98% of the catch was undersized (and hence illegal).
- A significant amount of catch from the *Estai* was recorded in the logbook of another Spanish vessel, the *Patricia Nores* (Harris 1998).
- Forty-five percent of all Spanish catches of flounder (*Platichthys flesus*) are said to be discarded at sea and not reported (Harris 1998).
- In the late 1980s, every haul of the trawl by Russian vessels was estimated to be under-reported by at least 10 tonnes (Internal DFO document, quoted by Harris (1998).

A number of correspondents providing information to the Sea Around Project have stated that, at least at this stage, they wish to remain anonymous, but, rather than being discarded as though it did not exist, we consider that this information may be used to provide a better estimate than zero for total extractions from these fisheries, and where confidential figures are challenged, the obligation is to provide a transparent estimates of the contested amount. Some examples are:

- In France, large quantities of 25–30 cm cod are illegally landed (two correspondents).
- In western Ireland, the true catch of large midwater trawlers targeting herring (*Clupea harengus*) and mackerel (*Scomber scomber*) is estimated to be at least double the reported catch quota of 50 000 tonnes (one correspondent).
- Between 20 and 50% of the catch of Scottish purse seiners in the 1990s was illegal (two correspondents).
- Unreported catch is said to equal reported catch for Humberside fisheries, and higher figures applied to historical periods of distant water fleets before the EEZs (one correspondent).
- In Denmark, cod landings are often disreported as dogfish (*Scyliorhinus stellaris*) (one correspondent).

Method

Our estimation method allows the use of all available specialist studies and information on unreported catches in a given fishery, along with their uncertainty, and synthesizes them into a single analysis. Sources of information can be weighted by their credibility in Monte Carlo simulations.

Basis of the adjustment method

The procedure to adjust reported catches is based on a spreadsheet divided by decade (or other appropriate time periods), and by category of misreported catch (discarded, illegal and unreported). Adjustment factors for each time period respond to changes in the regulatory regime, and hence the incentives and disincentives to misreport. Quantitative values are assigned to the adjustment factors, which are used as fixed anchor points when supported by reports and information explicitly attributed to a variety of sources, published and unpublished, and interpolated up or down using 'influence factors' when information is not quantitative. Confidence intervals around estimates of total misreporting for each period in the analysis are obtained using a Monte Carlo simulation based on likely error ranges. The technique can easily be adapted as more species, more fisheries or more reliable anchor points are added to the analysis. Here, we demonstrate the method for two national fisheries: Iceland, where there are plentiful, reliable data on landings by species; and Morocco, where data are more sparse.

Case study 1: Iceland

Despite recent concern over an unexpected drop in cod stocks, in general, Icelandic fisheries are believed to be well-managed and to have overcome many of the economic problems often associated with national fisheries (Arnason 1995). Major fisheries exist for both pelagic and demersal species. The pelagic fisheries, mainly capelin (Mallotus villosus), herring (Clupea harengus) and blue whiting (Micromesistius poutassou), provide the bulk of the catch, but the demersal fishery provides most of the revenue, generating approximately 75% of the total value of catches (Arnason 1995). Major demersal species are cod. haddock. 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). The EEZ has also resulted in limited trawling in large areas around Iceland. Real-time area closures used since 1976 have had similar effects. For detailed descriptions of the history of Icelandic fisheries since the beginning of the last century, see Arnason (1995) and Valtýsson (2002).

Discarding in Icelandic waters has been illegal since 1996 but it 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 50 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.

Estimating the effects of influence factors

Important historical changes to Iceland's regulatory regime are given in Table 1. 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 an incentive for fishers to discard low-valued fish in order to fill the hold or quota with fish of the greatest value ('high-grading': see Rettig 1986; Squires and Kirkley 1991; Anderson 1994; Walters and Pearse 1996; Turner 1997; for discussion of the effects of quotas on discarding). Technological advances in Icelandic fisheries increase the likelihood of bumper catches and, therefore, increase the incidence of discarding, whereas changes such as regulatory increases in mesh size and the introduction of devices such as sorting grids on trawl nets have probably had the opposite effect. 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 the quota system, some vessels have been caught concealing catches of cod under layers of saithe (which has a much lower value than cod) and falsely reporting the whole catch as saithe.

Certain species, particularly haddock, Atlantic halibut, common skate (*Dipturus batis*), and Greenland shark (*Somniosus microcephalus*) are caught mainly for domestic consumption. These species are commonly eaten by fishers at sea and a certain amount can also legally be taken home for the family. These amounts are unmandated in that they are not required to be reported. Comparison of estimates of local consumption of seafood obtained from official

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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 (\downarrow)	120 mm in codend enforced in 1963 (↓)	135 mm (1976) and 155 mm (1977) in codend enforced (\downarrow)		
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 iuveniles (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 (\uparrow), Powerblock (\uparrow)	Loran (↑)	Computerized jigging reels, Rockhoppers (\uparrow), Headline and codend sensors (\downarrow)	Computers (\uparrow), GPS (\uparrow), Sorting grids (\downarrow)

processing statistics (5523 tonnes; Anonymous 1999a) and estimates obtained by a survey of Icelanders' diets (12 352 tonnes; Anonymous 1999b) reveal a discrepancy of 6829 tonnes, implying that many more fish are landed than are reported. More than 70% of locally consumed fish is haddock (Anonymous 1999a), and the figures above suggest that haddock landings are underestimated by almost 5000 tonnes (equivalent to approximately 12% of the reported catch). Species which are mainly exported (such as cod) are monitored much more closely from the place of landing, through processing, to the 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. For example, some fishers have been caught with far more fish than they or their families could have eaten themselves, and a particular fisherman admitted that he had sold, on the black market, 200 tonnes of fillets in 1 year, equalling about 500 tonnes of live fish (Anon 2000). Although the extent of this practice is not known, a recent poll found that 20% of 1638 fishers interviewed have witnessed illegal landings of fish in Iceland and 76% believe that illegal landings occur (Anonymous 2001). It is expected that such illegal landings would have increased since the introduction of the quota system, especially in recent years when quotas have been expensive.

Methods

Clearly, there are complex factors influencing incentives to misreport catches, some of which seem to have conflicting effects. Incentives are based on knowledge of the history of the fishery (listed in Table 1), while Table 2 gives estimates of incentives to misreport for Icelandic fisheries between 1950 and 2000. 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, ...) is, at this stage, arbitrary. Influence factors are meant to give an indication of relative differences in the magnitude of misreporting among periods. To convert these qualitative estimates into meaningful figures, informed anchor points were needed for at least some periods. Table 3 gives estimates of misreporting of cod and haddock by gear-type, according to six different sources. To allow meaningful comparison of estimates-by-gear, proportion of mean total catch taken by each gear type (Table 4) was used to re-scale the estimates (Table 5). Because the estimates were now proportional to the total catch taken by all gears, they could be added to produce 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 required estimates (see Table 5). Table 2 suggests that factors affecting discarding were relatively stable between 1985 and 2000. Blank cells were, therefore, filled in by interpolating literature estimates from adjacent cells into blank cells for the periods since 1985 (values in italics, Table 6).

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 2-20% 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 interpolating the ranges found in Table 6 back to previous periods. Using the influences in Table 2 as a guide, the following percentage ranges were assigned: none = 0-1%; low = 1-3%; low/medium = 2-6%; medium = 3-12%; medium/high = 4-24%; high = 5 - 25% +.

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 were, unfortunately, no quantitative anchor estimates for the magnitude of illegal landings, although these are known to occur (Anon 2000). Table 8 gives estimates of missing catch, obtained by multiplying mean reported catch (Table 9) by interpolated estimates of misreported catch (Table 7). Table 10 then presents estimates of total extractions for Iceland from 1950 to 1998.

Table 2	ncentives for Ic	elandic vessels to	discard based	l on changes in	management	and technology	y given in Tabl
Fleet	Species	Туре	1950–1954	1955–1959	1960–1964	1965–1969	1970–1974
Iceland	Cod	Discards Illegal	L/M ^a N ^f	L/M ^a N ^f	L/M ^a N ^f	L ^b N ^f	L ^c N ^f
	Haddock	Unmandated Discards Illegal	N'' L/M ^a N ^f	N'' L/M ^a N ^f	N'' L/M ^a N ^f	N'' L ^b N ^f	N'' L ^c N ^f
Foreign	Cod	Unmandated Discards	L/M ^j L/M	L/M ^j L/M	L/M ^j L/M	L/M ^j L	L/M ^j L
		Illegal	N	N	N	N	N
	Haddock	Discards Illegal	L/M N	L/M N	L/M N	L N	L N

Ta n in Table 1. L = low; M = medium; N = none.

1975–1979

L/M^d

N^f

N^h

N

L/M^j

L/M

L/M

Ν

Ν

L/M^d

1980-1984

L/M^d

Nf

N^h

N^f

L/M^j

L/M

Ν

Ν

L/M

L/M^d

1985-1989

Me

Гa

Nh

Me

L/Mⁱ

Mk

М

1

Μ

L/M

1990-1994

Me

Гà

N^h

Me

L/Mⁱ

Mĸ

М

1

Μ

L/M

1995-2000

Me

Γa

N^h

М^е

L/Mⁱ

Mk

М

L

М

L/M

Notes: Illegal catch refers to illegal landings rather than discards. Unmandated catch refers to fish legally eaten or taken home by fishers.

^aEEZ 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.

^b120 mm cod end enforced.

^cEEZ extended to 50 miles, reducing trawling.

^dUndersized fish confiscated. EEZ extended to 200 miles. Effort control on Icelandic boats. Real-time area closures to protect juveniles.

^eIntroduction of ITQs in 1984.

^fNo ITQ system in place, mandatory to report all landings.

^gIntroduction of ITQs in 1984.

^hCod rarely eaten locally.

ⁱIntroduction of ITQs in 1984. Probable local black market for haddock.

^jFish legally taken home by fishers.

^kGreater incentive to land more fish in this way after introduction of quotas.

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

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.

Note: Bottom trawl includes lobster trawlers and shrimp trawlers.

^aGunnarsson (1995): Results of questionnaire returned by 591 fishermen.

^bPálsson (2001): Comparison of size composition from landings and those observed at sea.

^cAnonymous (2001a): Results of Gallup International questionnaire returned by 1638 fishermen.

^dAnonymous (1993): Comparison of landed catch of trawlers and catches observed at sea.

ePálsson (2002): Comparison of length distributions measured at sea with landings.

^fAnonymous (1999a,b): Comparison of processing statistics and survey data (see text).

Table 4	Proportion of mean	total catch of cod an	d haddock taken	by five different	demersal gear typ	pes. Proportions are
rounded	to two decimal place	s.				

Species	Gear	1980–1984	1985–1989	1990–1994	1995–1999
Cod	Handline	0.03	0.05	0.07	0.10
	Lonaline	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

Note: Catches taken by other gear types (driftnets, seiners, mid trawlers and others) were each less than 0.5 of total catch and are not listed.

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

Results suggest that Icelandic cod catches may have been underestimated by between 1 and 14%, and haddock by between 1 and 28%. sand samples were taken from triangular distributions, assumed between the lower and upper estimates of total missing catch for each period. Results are shown as error bars on Fig. 2.

Monte Carlo simulations

Monte Carlo simulations were used to investigate the effects of uncertainty in influence factors and anchor points on estimates of total missing catch. Five thou-

Discussion

This analysis is incomplete without total extractions of all species, including non-commercial fish, caught

Species	Gear	1980–1984	1985–1989	1990–1994	1995–1999
Cod	Handline		0.20		0 21-2 26
000	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 trawls		0.54–5.43	5.6-13.73	3.49–14.96

 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 3 with (unrounded) proportions in Table 5.

Note: Proportions shown in Table 4 were rounded for presentation. Unrounded proportions were used to calculate the percentages in the above table.

 Table 6
 Interpolated estimates of discarding by gear (italics; non-italics are anchor points). 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	Handling		0.20	0.20.2.26	0.21.2.26
Cou			0.20	0.20-2.20	0.21-2.20
	Danish Soino		0.06 2.42	0.06	1 49 2 42
	Danish Seine		0.00-2.42	0.06	1.40-2.42
	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 trawls		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

in Icelandic waters. 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 Anonymous 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 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 to them appropriate estimates of misreporting obtained from reliable sources for similar species. A major project has recently been initiated by the Icelandic government to compare catches by boats with observers

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with landings by boats without observers, to gain better estimates of discarding.

Case study 2: Morocco

In many countries, particularly in tropical regions where mixed-species fisheries are common, detailed statistics are not collected. The following example illustrates an application of our methodology to such a data-sparse fishery in Morocco. For a detailed analysis of this fishery, see Baddyr and Guénette (2002).

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	Species	Туре	Limits	1950–1954	1955–1959	1960–1964	1965–1969	1970–1974	1975–1979	1980–1984	1985–1989	1990–1994	1995–1999
Iceland	Cod	Discards	Lower	0.02	0.02	0.02	0.01	0.01	0.02	0.02	0.045	0.011	0.031
			Upper	0.06	0.06	0.06	0.03	0.03	0.06	0.06	0.098	0.064	0.11
		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	0.016	0.063	0.044
			Upper	0.06	0.06	0.06	0.03	0.03	0.06	0.06	0.082	0.18	0.20
		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	0.045	0.011	0.031
			Upper	0.06	0.06	0.06	0.03	0.03	0.06	0.06	0.098	0.068	0.11
		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	0.016	0.063	0.044
			Upper	0.06	0.06	0.06	0.03	0.03	0.06	0.06	0.082	0.18	0.20
		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

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	Туре	limit	1950–1954	1955–1959	1960–1964	1965–1969	1970–1974	1975–1979	1980–1984	1985–1989	1990–1994	1995–1999
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

Table 8 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.

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leet	Species	1950–1954	1955–1959	1960–1964	1965–1969	1970–1974	1975–1979	1980–1984	1985–1989	1990–1994	1995–1999
celandic	Cod	237541	284755	251557	232095	251103	311180	369110	361764	267408	210549
	Haddock	20143	26044	51199	39312	32490	39905	57376	50274	54180	+ 48953
oreign	Cod	182815	202586	162513	144424	165175	39563	5692	2469	1343	583
	Haddock	34862	41295	52024	24607	11150	5385	2239	1283	1174	588
ource: ICES	3 and Iceland Nati	ional Data, provided	by H. Valtýsson.								

fleet, which is made up almost exclusively 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 (Baddyr and Guénette 2002). 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 fishermen (similar to the unmandated landings in Iceland), illegal sale of fish and mistakes in weighing the catch.

Table 11 shows estimates of discarding and underreporting obtained from several sources. 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, anchor estimates were interpolated directly into blank cells if the influences were considered to be the same (an alternative method when few periods are under consideration). Where there was no range in the anchor points, interpolated estimates were given an arbitrary upper and lower bound of $\pm 5\%$ (Table 12). In support of this value, anchor ranges, where obtained, ranged from 4 to 13% in any particular period (see Table 11) and our upper and lower bounds of \pm 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 the Monte Carlo simulation described above. Results are shown in Fig. 3. Overall, our analysis suggests that Moroccan catches appear to have been under-reported by as much as by 50%.

Discussion

Records of exact species compositions of Moroccan landings do not exist. For example, reported landings of demersal species in Morocco were dominated by an unidentified mixture of species, as were a large part of the foreign catches (Baddyr and Guénette 2002). When the composition of the reported catch is not known, we cannot quantify the magnitude of misreporting for individual species but it is possible, however, to at least identify some of the species that make up the unreported catch.

Discarding. Sardines (*Sardina pilchardus*) comprise the majority of the both the pelagic catch (approximately 94% of the total catch: Oueld Taleb 1988) and discards, dumped either at sea or during net cleaning (El Mamoun 1999). As discarding by pelagic fleets is

Table 9 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.

Table upper estima
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Fable 10 Estimated total extractions (tonnes) of cod and haddock obtained by adding reported landings (Table 8) to estimated missing catch (Table 9). Grey cells are percentages. Lower and
apper 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	1950–1954	1955–1959	1960–1964	1965–1969	1970–1974	1975–1979	1980–1984	1985–1989	1990–1994	1995–1999
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



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 thick line shows the mean of 5000 Monte Carlo samples (see text). Error bars represent upper and lower 95% confidence intervals. Lower error bars are truncated at reported total catch (thin line).

considered to be less than 5% of the total catch (Table 12), the quantity of discards of other pelagic species is probably not significant (less than 0.3% of the total catch). In demersal fleets, coastal bottom trawlers, which landed more than 90% of the Moroc-can 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 catsharks (*Scyliorhinus canicula*), sabre argenté (*Lepidopus caudatus*), congers (*Conger conger*), crabs, rays **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).

Fleet	Fishery	Туре	1970–1979	1980–1989	1990–1999
Coastal Morocco	Pelagic	Discards			0–4 ^a
	Demersal	Discards			5 ^d -13 ^a
	All	Unreported		23 ^b	47 ^a -60 ^c
Industrial Morocco	Pelagic	Discards			0 ^e
	Demersal	Discards	66 ^d	46 ^d	30 ^e
	All	Unreported			47 ^a -60 ^c

^aEl Mamoun (1999). ^bEl Hannach (1986). ^cDurand (1995).

^dBalgueřías (1997). ^eHaddad (1994).

Table 12Interpolation (italics) of estimates of misreporting for Moroccan fisheries from 1970 to 1999. Reasons forinterpolations 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	Туре	1970–1979	1980–1989	1990–1999
Coastal Morocco	Pelagic	Discards	0-4 ^a	0-4 ^a	0-4
	Demersal	Discards	$\mathit{30^{b}} \pm \mathit{5}$	$20^{ m c}\pm 5$	5–13
	All	Unreported	$23^{ ext{d}} \pm 5$	23 ± 5	47-60
Industrial Morocco	Pelagic	Discards	No industrial fleet	$\mathit{0}^{e} \pm \mathit{5}$	0 ± 5
	Demersal	Discards	66 ± 5	46 ± 5	30 ± 5
	All	Unreported	47-60 ^f	47-60 ^f	47-60
Foreign	Pelagic	Discards	$0^{ m e} \pm 5$	$\mathit{0}^{e} \pm \mathit{5}$	$\mathit{0}^{e} \pm \mathit{5}$
	Demersal	Discards	$66^{ ext{g}}\pm5$	$46^{ ext{g}}\pm5$	$30^{ ext{g}}\pm5$
	All	Unreported	23-47 ^h	<i>23</i> –47 ^h	<i>23–47</i> ^h

^aDiscarding was never very high and is probably decreasing with the use of freezer boats.

^bAssumed to follow the same trend as the industrial fleet (see below).

^cAssumed to follow the same trend as the industrial fleet (see below).

^dAssumed equal same as the 1980s because same economic context for market for fish in Morocco.

^eAssumed to be the same as for the 1990s.

^fAssumed higher than for coastal fleet because there were landings outside the country (Canaries).

^gAssumed the same as for the industrial fleet because most observer information used for the industrial demersal fleet comes from foreign vessels.

^hAssumed 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.

and rockfishes (El Mamoun 1999). The composition of species discarded by Spanish cephalopod trawlers consisted mainly of seabream (Sparidae), other unidentified demersal finfish, 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 or for Moroccan industrial demersal vessels.

Under-reporting. Durand (1995) reported that up to 60% of Moroccan catch, especially valuable species like mackerel and anchovies, may be marketed

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 Table 13
 Estimates of total extractions (tonnes) of marine organisms from the Moroccan fishery for the period 1970–99. Values in italics are percentages. Lower and Upper refer to the top and bottom of the estimated range of misreporting for each period.

Fleet	Fishery	Туре	1970–1979	1970–1979		1980–1989		1990–1999	
			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 landings percentage	18	28	18	28	47	60	
		Discards percentage	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	62900 94350 23497 60 13 180747	
		Discards	9193	16913	16983	36534	6246		
		Unreported landings (%)	18	28	18	28	47		
		Discards (%)	25	35	15	25	5	13	
		Total estimated	36773	48323	113217	146134	124926	180747	
Industrial Moroccan	Pelagic	Reported landings			26394	26394	29294	29294	
Morocoan		Unreported landings	No industrial		23406	39591	25978	43942	
		Discards	pelagic fleet		0	3473	0	3855	
		Unreported landings (%)			47	60	47	60	
		Discards (%)			0	5	0	5	
		Total estimated extraction			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 landings (%)	47	60	47	60	47	60	
		Discards (%)	61	71	41	51	25	35	
		Total estimated extraction	29016	51703	202942	323776	243449	372196	
Foreign	Pelagic	Reported landings	850871	850871	832512	832512	724680	724680	
	<u> </u>	Unreported landings	254156	754546	248672	738265	216463	642641	

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820/3	47	5		1653450	1653450 238261	1653450 238261 211288	1653450 238261 211288 467898	1653450 238261 211288 467898 47	1653450 238261 211288 467898 47 51	1653450 238261 211288 467898 47 51 917448
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Discards	Unreported landings	Discards (%)	Total estimated extra		Reported landings	Reported landings Unreported landings	Reported landings Unreported landings Discards	Reported landings Unreported landings Discards <i>Unreported landings</i>	Reported landings Unreported landings Discards <i>Unreported landings</i> <i>Discards (%)</i>	Reported landings Unreported landings Discards <i>Unreported landings</i> <i>Discards (%)</i> Total estimated
					Demersal	Demersal	Demersal	Demersal	Demersal	Demersal

through illegal channels to avoid taxes. 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 Canary Islands), and we can assume that the composition of catch unaccounted for in this period is similar to the composition of today's commercial catch. 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

Unreported extractions cast various kinds of shadows on fisheries and their associated activities. These shadows can help us track them. The methodology presented here offers a transparent and simple way of estimating unreported catches, using information from a variety of sources. Estimates 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. Information provided in confidence may be challenged, but publication of provisional estimates may encourage more transparency.

The method has a difficulty in that we use a percentage of the reported catch. How do we deal with the problem where no catch is reported, yet discards and illegal catch are known to occur? Patterson (1998) considers it easier to estimate catch 'reporting efficiency' (i.e. accuracy) than to make absolute estimates of unreported catch. But the key here is that we are interested in an annual value for whole ecosystems. Therefore, attempts should be made to raise figures in tonnes to annual values and compare these with the annual catch of the species over the whole system. In the method, our influence factors remain the same, and if anchor points are given in absolute terms, the answers will be in the same modality if desired.

So far, most of the information used to anchor estimates has come from published reports, news items or university theses, although where personal comments or other sources given an estimate of reliability can be used. When setting the anchor points, for example, informants may be asked to rank the severity of unreported catches. In fact, humans are quite good at ranking things presented in pairs, asking the question 'which is the better and which is the



Figure 3 Estimated total extractions of demersal and pelagic species from Moroccan waters, compared with reported catch, for all fleets combined. The thick line shows the mean of 5000 Monte Carlo samples. Error bars represent upper and lower 95% confidence intervals. Lower error bars are truncated at reported total catch (thin line).

worse?' A series of paired questions might be developed for a more formal protocols here.

The results we obtained for Icelandic cod and haddock are only 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. The most 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 and because there was a consistent trend among gear-types, we chose to recognize this as a real trend and upgraded our estimate of the influence factors for this period. In other cases, an 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 under-reporting, even when data is 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.

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, 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 and differing reliabilities will have correspondingly different error ranges. We will have to persist with anonymous informers (all of whom are highly reputable fishery scientists or they would not have been contacted for information in the first place!), until such time as the pressure to correct our figures forces those with better data to break cover.

Benefits from a transparent new method

Murawski (1996) has looked at factors influencing discards in data from the US and Canada. General linear models were fitted to discard rates, total catch, species richness, species diversity evenness, together with operational variables associated with the fishing process (codend mesh, vessel size, tow duration, total catch, target species, year, month, depth and statistical area). Variances were high, but fisheries managed by mesh and fish size generally had higher discard rates. Year classes with high abundance influenced discard rates disproportionately. Murawski worked with observer estimates of discards, whereas the focus of this paper is to suggest a method to use when such data is not available.

In the ICES area, estimates of illegal fishing are routinely made by the stock assessment working parties that regularly perform single-species stock assessment. Yet, it is an unwritten but strictly imposed tradition that the basis of such adjustments are not made public, even when officials have direct knowledge of specific events. Such a policy of secrecy would likely be news for the public of the countries involved. Covering up for illegal fishing would be unthinkable if this were illegal drug running. Bank staff who defraud the public of millions of dollars are not protected by a shield of anonymity – so why should this protection be afforded to illegal fishers?

Evaluation by FAO of IUU fishing

Bray (2000) reviews IUU experience world wide, and points the finger at flag states for not providing adequate human and financial resources to tackle the problem. In this work, FAO has published a strong message concerning the critical importance of IUU fishing to the sustainability of benefits from capture fisheries. For example, Evans (2000) considers that IUU fishing distorts and devalues information from compliant fisheries, lowers allowable catches set using the precautionary approach, and increases uncertainty and the risk of over-exploitation. Evans considers that, at national scales, there is often complacency about the intractability of the problem, echoing our concerns expressed above. Evans considers some fisheries, where new technology has recently made deep-water or marginal stocks vulnerable, to be under-reported by as much as 75%, and in the case of stocks on the high seas, over 100%. Evans sees compliance with FAO Code of Conduct for Responsible Fisheries (see Edeson 1996; Doulman 1998) as an essential first step in improving the situation. Doulman (2000) also considers IUU to be major flaw in present fisheries management, leading to a loss of economic and social benefits, and, in extreme cases, to the collapse of stocks. Doulman (2000) calls for a protocol that can operate regionally, subregionally and nationally, and be applicable to different types of fisheries and stock distributions. We offer the method set out here as an starting point for such a protocol.

Finally, Edeson (2000) reviews the legal remedies available to combat IUU fishing. In particular, the possible role of the FAO Code of Conduct as an instrument of international law and a part of an International Plan of Action. Within the EEZs of nations, although some national laws might be improved, the problem is more a lack of implementation of existing regulations. Edeson considers this situation might be improved by explicit adoption and enforcement by of the FAO Code of Conduct by the flag state of the vessel.

Cheating is widespread in fisheries, the penalties are low, and the risk of detection as the participants are well aware, is often low, Unfortunately, political disincentives lead many concerned with fisheries to downplay their knowledge of this cheating. Where government and official sources have strong links, and even funding, from industry, we may expect these disincentives to be stronger. Fraud on this scale has not only contributed to the depletion of marine ecosystems and contributed to disastrous stock collapses, but has foreclosed options for the future generation of wealth and sustainable benefits from marine resources. Like any other criminal act, we need to estimate the true magnitude of unreported and illegal fishing.

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