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Estimating illegal, unreported and unregulated catch in British Columbia's marine fisheries

C.H. Ainsworth *, T.J. Pitcher

Fisheries Centre, 2259 Lower Mall, University of British Columbia, Vancouver, BC, Canada V6T 1Z4

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Abstract

To fully understand the impact of fishing on the marine environment, it is necessary to have an estimate of total extractions from the ecosystem. In addition to nominal fisheries landings and reported discards, which are regulated and monitored, removals will include a certain amount of illegal, unreported and unregulated catch (IUU). This amount, if considered, might profoundly affect our forecasts of stock abundance and safe removal rates. Here, we present preliminary estimates of the quantity of IUU catches over time for the British Columbia salmon and groundfish fleets. Based on influences in the history of the fisheries, and on independent estimates of misreporting, our methodology employed a Monte Carlo routine to determine missing catch with an associated error range. From the 1950s to the 1980s, we estimated that between 10,000 and 20,000 tonnes of catch went unrecorded every year in the BC salmon and groundfish fisheries. IUU catch increased throughout the 1980s, and by 1990 the amount was probably closer to 30,000 tonnes per year, equivalent to 18% of recorded landings. At present, less catch is unaccounted for thanks to tighter monitoring and enforcement: about 8000 tonnes per year, or 6.6% of landings. Values calculated here, using this subjective but transparent methodology, are intended to provide a starting point for further discussion and amendment.

Keywords: Illegal fishing; Unreported catch; Unregulated catch; IUU; Salmon; Groundfish

1. Introduction

To fully understand the ecological impact of fishing on the marine environment, it is necessary for biologists to have some estimate of total extractions from the ecosystem. In addition to nominal fisheries landings and reported discards, which are regulated and monitored, removals will include a certain amount of illegal, unreported and unregulated catch (IUU). Quantifying these removals can present a significant technical challenge if, for certain fisheries and species, regulatory agencies hold no mandate to record catch statistics. The difficulty is compounded by the politically sensitive nature of the question. Sometimes governments are reluctant to reveal the scope of catch that escapes notice, or to embarrass particular sectors engaged in

* Corresponding author. Tel.: +1 604 822 1639; fax: +1 604 822 8934.
E-mail address: c.ainsworth@fisheries.ubc.ca (C.H. Ainsworth).

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'dirty' or illegal activities, and fisheries agencies may have few incentives to attempt to estimate the quantity of unreported catch.

In the absence of reliable estimates, some assume an implicit 'zero' quantity for these elements (Pitcher et al., 2002). It is a potentially dangerous assumption. If considered, the missing catch could profoundly affect estimates of stock abundance and safe removal rates. When managers are forced to set harvest goals without knowing at least the magnitude of catch left unaccounted for, we put fisheries and ecosystem services at risk. If the missing quantities are significant, then not only can "blind" management jeopardize ecosystem structure, but fisheries benefits could also be compromised, since a precautionary and ecosystem-based approach to management demands conservative harvest regulations (Evans, 2000). Moreover, the presence of IUU fishing distorts and devalues information obtained from compliant sectors, often at their own expense.

Here, we present a methodology to estimate the quantity of IUU catches over time, based on influences in the history of the fishery, and on independent estimates of misreporting. We used a Monte Carlo routine to determine missing catch with an associated error range for British Columbia salmon and groundfish fisheries. Although any reasonable estimate of IUU would be better than a zero-rate assumption, the values calculated here, using this subjective but transparent methodology, are intended to provide a starting point for further discussion and amendment.

1.1. What is IUU?

For many fisheries, the largest component of IUU will be discarded bycatch, which may or may not be illegal, but is generally not recorded by fishery observers. Illegal catch refers to catch deliberately concealed, or misreported as other species to contravene regulatory limitations (such as time or area closures, species quotas, gear restrictions and so on). Illegal catch may also include unreported harvests landed in foreign ports or trans-shipped to foreign vessels at sea. Illegal catch is the most difficult component of IUU to quantify as an accurate record may be hard to obtain, even from surveys, if fishers are reluctant to contribute for fear of incriminating the industry—while the presence of onboard observers is likely to curb such activities altogether. Finally, IUU will include unregulated catches of species which authorities are not mandated to monitor, or harvests originating from certain vessels or gear types that are not subject to strict accounting.

1.2. BC case study

In west coast Canadian fisheries, the only IUU component regularly assessed is discards for the groundfish trawl and hook and line fleets. Efforts to quantify discarding through use of on-board observers have been limited to large vessels. Although observer coverage is now very high (100% of vessels are covered, but not for 100% of the time) for groundfish trawl, coverage is not adequate in the hook and line fleet (Haigh et al., 2002). Where it is assessed, time-series discard information extends back barely a decade. Although attempts have sometimes been made to quantify missing catch through statistical techniques (e.g. Patterson, 1998), no reliable estimates are published for BC (A. Sinclair, Department of Fisheries and Oceans, Pacific Biological Station, Nanaimo, pers. commun.).

Here, we examined discards and illegal catch present in the major fishing sectors for salmon (gillnet, troll, seine and recreational) and groundfish (bottom trawl, hook and line and recreational). Discards in the salmon and groundfish fleets were assumed to contain both 'unreported' and 'unregulated' catch, but we did not try to distinguish them. A separate analysis of the salmon recreational fleet provided epstimates of missing catch, which we termed 'unreported'.

2. Methods

2.1. The estimation procedure

To estimate missing catch we used a technique similar to Pitcher et al. (2002). For example, Pitcher and Watson (2000) estimate IUU for Atlantic Canada, Pitcher et al. (2002) look at Iceland and Morocco (also Forrest et al., 2001), and Kalikoski et al. (in press) consider Chile. The methodology can be broken down into seven steps:

1. Create a timeline of the fishery—taking note of regulatory, technological and political changes that are likely to have affected the quantity of fishery discards, illegal, unreported and misreported catch.

2. Assign 'influence factors' to each event (usually increase or decrease), to describe the effect on IUU rates.
3. Based on the frequency and severity of influences, assign an 'incentive' rating (e.g. low, medium or high) to describe the overall incentive to misreport for each 5- or 10-year period in the timeline.
4. Establish an absolute range of values for each 'incentive' rating (e.g. in percent IUU catch per target species catch)—these are based on fixed 'anchor points', quantitative estimates of IUU available from the literature or by expert opinion.
5. Scale absolute IUU estimates for missing periods, based on relative 'incentive' rating.
6. Using the range established in step 4, provide an estimate of total extractions for each fishery (reported plus missing catch), weighing the contribution of each gear type to IUU by its mean reported catch. For each period, estimates will contain a lower and upper bound. If possible, determine a 'best guess' estimate within the total range.
7. Use Monte Carlo resampling to determine the mean weight of missing catch with associated confidence intervals for each period, based on the likely error range established in step 6. Previous authors have assumed an asymmetric triangular distribution around a specified mode (the 'best guess').

2.2. Revisions to the methodology

The method used in this paper has been modified from previous case studies. Other authors combine fishery discards, illegal catch, and other unreported or unregulated sources of catch into a single quantity, IUU, assuming that influence factors affect each component equally. However, it is likely that certain regulatory, technological and political changes will affect the categories of IUU differently. For example, an area closure for the trawl fleet meant to protect sensitive benthic habitat may reduce discarding of non-target benthic organisms, but at the same time will introduce an opportunity for poaching groundfish. So, in this paper we have expanded the methodology to consider these IUU categories separately. We developed an independent history of influences for each type of IUU based on the literature review by Ainsworth and Pitcher (2004, Appendix Table A.1). Categories of IUU examined are discards (including both unreported and unregulated catch), illegal catch, and unreported catch. We constructed three absolute trends using independent anchor points for discards, illegal, and unreported catch. Parallel analyses were conducted and then combined to provide an estimated sum of IUU. By keeping these IUU components separate in the analysis, we hope that the technique will be more flexible and adaptable to any fishery. The relative quantities of missing catch in each category will also signal to managers what actions are required to reduce misreporting.

2.3. Influence factors

We have also tried to introduce a more precise methodology to assign influence factors. Where other authors allocate to each historical event a simple influence factor indicating an 'increase' or 'decrease' in the rate of IUU catch, we have refined the ranking into minor and major influences. This system can be used to discriminate significant from routine changes in the fishery, or it can be used to restrict the influence of certain events if they affect only a portion of the fleet or study area. The assumption introduced here is that minor influences have half the effect of major influences in determining the rate of misreporting.

We then created a numerical running total throughout the time series, where major positive influences added 1.0 to the cumulative score, and minor positive influences added 0.5; negative influences subtracted the same. In this way, events that have duration will contribute, and then withdraw from the ranking; multiple events will be additive, and so on. The influence table (in Ainsworth and Pitcher, 2004, Appendix Table A.2) considered 154 events in the history of BC fisheries since 1950 which are likely to have affected IUU rates, including changes in management and politics, as well as technological and market developments. Table 1 provides a short excerpt from the time line detailing historical events that occurred between 1970 and 1979.

2.4. Quantifying incentive

Previous authors use a subjective and arbitrary technique to assign each historical period a 'low', 'medium' or 'high' incentive rating based on their general impression of the severity and frequency of influences within that period. To standardize the process of quantifying incentives, we divided the total amplitude of the numerical influence trend into five

Table 1
IUU influences table (excerpt from Ainsworth and Pitcher, 2004)

Period	Event summary[a,b]				Refs.[c]	Influence[d]			Affected flee[e]							Rationale[f]	Duration[g]		Termination
	Policy	Technology	Political	Supply/market		Discard	Illegal	Unreport.	Salmon				Groundfish						
									Gillnet	Troll	Seine	Rec	Trawl	H&L	Rec				
1970–1974	New rockfish regulations				82	▲		▲					√	√		Rockfish misreporting increases to contravene restrictions	1970	1980	DFO regulations
				"Cold chains" introduced	128	▼			√	√	√		√	√		Cold chains open a market for less valuable species previously discarded	1970	2003	
	POP closure (QCS)				57	▽	△						√	√	√	Affects only a portion of study area (QCS); opportunity for poaching	1971	1974	
1975–1979				Poland fleet enters	127	△							√	√		Increased catching power; rockfish targeted; light Polish presence	1975	1977	EEZ Formed
		Larger fishing vessels			105	▲			√	√	√		√	√		Increased catching power, longer trips	1975	2003	
	Additional rockfish/ flatfish spp. targeted				122	▼		△					√	√		Bycatch retained and sold; data collection inadequate for rockfish	1975	2003	
	Trip limits GF trawl				128	▲		△					√			Fishers can no longer land everything they catch; incentive to high grade, misreporting as other species	1976	2003	
			EEZ formed		8,31	▼	△	▼	√	√	√		√	√		Reduced catching power (foreign restricted); opportunity for poaching; better monitoring of domestic fleet than foreign fleet	n/a	n/a	
				USSR/Japan rockfish fishery ends	127	▼	△	▼					√	√		Reduced catching power (foreign restricted); opportunity for poaching; better monitoring of domestic fleet than foreign fleet	n/a	n/a	
			SEP begins		51	△			√	√	√					CEDP assists fishers (subsidy); increased catching power	1977	2003	
			Legislation ends native commercial fishery		118		▲	▲	√	√	√		√	√		Opportunity for poaching; catch not reported	1977	1992	Pilot sales program
	Annual quotas set for GF				82	▲		△					√	√		Fishers can no longer land everything they catch; incentive to high-grade, misreporting as other species	1978	2003	
			DFO established		19		▼	▽	√	√	√		√	√		Enforcement improved; data collection improved	1979	2003	

Table 1 (*Continued*)

Period	Event summary[a,b]				Refs.[c]	Influence[d]			Affected flee[e]						Rationale[f]	Duration[g]	
	Policy	Technology	Political	Supply/market		Discard	Illegal	Unreport.	Salmon				Groundfish				
									Gillnet	Troll	Seine	Rec	Trawl	H&L	Rec		
	GF TAC, trip limits, closures, license limitations				82	▲		△					√	√	Fishers can no longer land everything they catch; incentive to high-grade, misreporting as other species	1979	2003

[a] Events listed in chronological order. See Ainsworth and Pitcher (2004, Appendix Table A.1) for additional description.
[b] Abbreviations: Pacific Ocean perch (POP); Salmonid Enhancement Program (SEP); economic exclusion zone (EEZ); Queen Charlotte Sound (QCS); Department of Fisheries and Oceans (DFO); groundfish (GF).
[c] Reference in Ainsworth and Pitcher (2004, Appendix Table B.1).
[d] Closed arrow, major influence; open arrow, minor influence (see rationale).
[e] Salmon troll includes all commercial hook and line methods.
[f] See text for conventions used.
[g] n/a, termination event for previous influence.

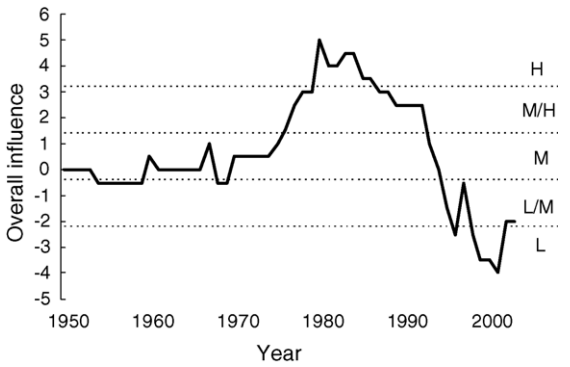

Fig. 1. A time series of numerical influence factors is assigned semi-quantitative "incentive" ratings: high (H), medium–high (M/H), medium (M), low–medium (L/M) or low (L). Example shows unreported catch for groundfish trawl.

categories: low, low/medium, medium, medium/high and high. Fig. 1 shows an example. Total influences affecting unreported catch for groundfish trawl begin with a 'medium' incentive score in the 1950s, indicating median levels of missing catch. Changes in the fishery increase unreported catch throughout the 1970s and 1980s to 'high', but by the 1990s the trend has reversed and incentives quickly fall to 'low'.

As here, all previous IUU studies under this methodology use five categories to describe the magnitude of the incentive factor—most authors have labeled these categories low, low/medium, medium, medium/high and high.

Table 2 shows the predicted incentives for each period and gear sector used in the analysis. Grey cells indicate periods where anchor points exist.

2.5. Anchor points

To turn the incentive ratings into a series of absolute catch, it is necessary to ground the relative trend using anchor points—examples of known discards, illegal and unreported catch taken from the literature and other sources. Table 3 indicates the range of estimates available in the literature for each of these IUU categories, shown as a percentage of reported catch for each gear type. Absolute quantities for the lower and upper bounds were calculated based on official catch statistics summarized in Table 4. Data is averaged over 5-year periods. Catch statistics were assembled by Ainsworth and Pitcher (2004, Appendix Table A.3).

Table 2
Incentive ratings

IUU category	Target Sp.	Fleet	Period										
			1950–1954	1955–1959	1960–1964	1965–1969	1970–1974	1975–1979	1980–1984	1985–1989	1990–1994	1995–1999	2000–2003
Discards	Salmon	Gillnet	H	H	H	H	H	H	H	H	M/H	L/M	L
		Trailer	H	H	H	H	H	H	H	H	M/H	L/M	L
		Seine	H	H	H	H	M/H	H	H	H	M/H	L/M	L
		Recreational	M/H	H	H	H	H	H	H	H	H	L/M	L
	Groundfish	Trawl	L	L/M	M/H	M/H	M/H	M/H	M/H	M	M/H	L/M	L/M
		Hook and line	L	L/M	L/M	M/H	M	M	M	M	M/H	M/H	M/H
		Recreational	L/M	M/H	M/H	M/H	M	M/H	M/H	M/H	H	M	L/M
Illegal	Salmon	All	H	H	H	H	H	H	H	H	M/H	L/M	L
	Groundfish	All	H	H	H	H	H	H	H	H	M/H	L	L
Unreported	Salmon	Recreational	H	H	H	H	H	H	H	H	H	L/M	L

Grey cells indicate periods for which anchor points exist.

Table 3
Anchor point range (% of catch per gear type)[a]

IUU category	Target Sp.	Fleet	Period										
			1950–1954	1955–1959	1960–1964	1965–1969	1970–1974	1975–1979	1980–1984	1985–1989	1990–1994	1995–1999	2000–2003
Discards	Salmon	Gillnet								5.0	6.0		0.0–10.0
		Trailer								5.0	5.0		
		Seine								5.0	5.0		
		Recreational									7.6	7.6	
	Groundfish	Trawl[b,c,d]			4.3–25.0	7.7–25.0	12.0–26.1	8.3–26.8	6.8–25.0	5.9–22.2	6.6–21.5	3.2–17.5	10.3
		Hook and line[e]								16.1–27.4	26.0–50.0	15.7–75.3	46.4–75.3
		Recreational[f]											21.0
Illegal	Salmon	All									0.1–0.15	0.1–0.15	0.1–0.15
	Groundfish	All									0.04	0.04	0.04
Unreported		Recreational							169	120	246	415	332

[a] References provided in Ainsworth and Pitcher (2004, Appendix Table B.1).
[b] Low estimate from 1962 to 1986 includes information from shrimp trawl fishery, we therefore assume GF trawl has similar discard/target ratio as shrimp trawl.
[c] Low estimate from 1974 to 1990 based on halibut bycatch and halibut landings; we therefore assume other groundfish have similar discard/landing ratio as halibut.
[d] High estimate from 1960 to 1969 based on subsequent decade.
[e] Low estimate from 1992 to 1994 includes information from Bering sea, 1988–1989 based on halibut hook and line.
[f] Datum from Oregon coast.

Table 4
Mean reported catch (tonnes)

Targets Sp.	Fleet	Period										
		1950–1954	1955–1959	1960–1964	1965–1969	1970–1974	1975–1979	1980–1984	1985–1989	1990–1994	1995–1999	2000–2003
Salmon	Gillnet	34082	25878	23906	24274	28549	16864	14968	21454	23117	11621	10630
	Trailer	11707	11229	11452	16454	17230	17231	18453	22513	19858	6940	2071
	Seine	36420	24764	21174	19947	26716	24154	31296	46927	36903	18431	16083
	Recreational	4114	3094	5653	6067	7250	5825	5125	7150	6722	2981	2092
Groundfish	Trawl	17426	17229	20862	20819	15246	22076	43431	49737	70402	83934	80682
	Hook and line	2312	2286	2768	2762	2023	1782	2317	4167	8720	10396	9993
	Recreational	–	–	–	–	–	–	1345	1397	680	898	792

Summarized from Ainsworth and Pitcher (2004, Appendix Table A.3).

2.6. Discards

Information regarding discards for the salmon and groundfish fisheries, includes data from experimental fisheries, onboard observer programs and predictive models. In some cases, data from outside BC has been used. In the case of groundfish trawl, we have often assumed that proportional discard data from the halibut fishery (which has the most information) can be applied without modification to other groundfish target species as well. See Table 3 for additional caveats.

2.7. Illegal catch

With regard to illegal catches, the anchor points provided in Table 3 represent a very rough first attempt at this quantity. Each year, the Department of Fisheries and Oceans (DFO) news releases record, for only a small proportion of incidents, the confiscated weight of illegally caught salmon, groundfish and other species taken by fishery officers during vessel inspections, road blocks, and other enforcement operations. No compendium exists, however, of total confiscated weight for any year, as the DFO Protection and Conservation Branch is not mandated to record that information along with the legal record of charges laid. In addition to the large number of incidents that presumably go unnoticed, the specific record of confiscated weights available in the news releases refers to only exceptional cases that are deemed newsworthy by the press (Anonymous, DFO, Victoria, pers. commun.). To accurately estimate the total weight of illegal catches occurring in the salmon and groundfish fisheries, rigorous surveys would be required. Under the scope of the present investigation, we have therefore made a critical assumption: that DFO news releases account for 10% of the total weight of fish taken illegally (including weight confiscated but not reported, and including illegal catch that goes unnoticed by authorities). In reality, DFO news releases probably account for a much smaller percentage of the total illegal catch, so our final estimate is bound to be conservative.

2.8. Unreported catch

Anchor points for unreported catches of the salmon recreational fleet were based on the discrepancy

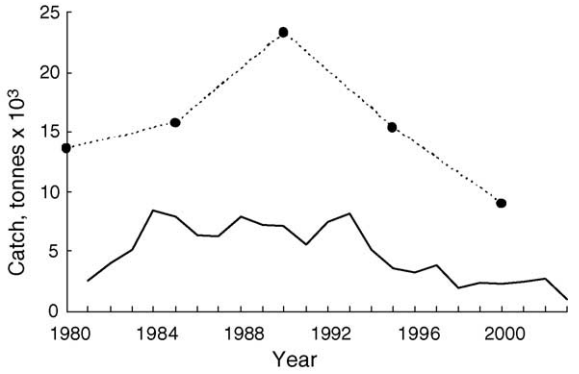

Fig. 2. Salmon recreational catch estimates. Solid line shows DFO Pacific Region estimates from creel surveys and logbooks, dotted line shows DFO Statistical Services Branch estimates from mail-out surveys.

between the two available datasets regarding sport catches in BC (Fig. 2). DFO Pacific Region conducts annual creel and logbook surveys (supplemented by aerial observations) to calculate recreational catch. These estimates can represent as little as one third of the total amount estimated by mail-out surveys, conducted every 5 years by the DFO Statistical Services Branch. The disagreement is likely due to differences in methodology, as the Pacific Region's creel estimates do not account for landings in many ports and do not capture activity on the shore or at private docks.

The rigor with which creel surveys are conducted has declined in recent years as fewer financial and human resources are being dedicated to the process. Moreover, the actual coverage for all creels is unknown, and is only assumed to be complete[1] (K. Brickley, DFO Statistical Services Branch, Ottawa, pers. commun.). Forrest (2002) discusses the discrepancy further. We have therefore assumed that the Pacific Region sport catch estimates represent the lower bound of the possible catch range, while the Statistical Services Branch estimates represent the upper bound—the difference being called 'unreported'. Both datasets refer to pieces retained, so we converted to wet weight using ratios reported in Ainsworth and Pitcher (2004, Appendix Table A.4).

[1] The two datasets for the BC recreational salmon fishery are progressively moving to agreement, as target stocks become more depleted (K. Brickley, DFO Statistical Services Branch, Ottawa, pers. commun.).

2.9. Addressing uncertainty

Once we identified a likely range for the quantity of IUU using the subjective procedure (i.e. a lower and upper bound), we employed a Monte Carlo technique to estimate the mean of missing catch with error for each time period. The true amount of missing catch (X) will fall somewhere in the estimated range between the lower bound (A) and the upper bound (C) so that:

$$P[A \leq X \leq C] = \int_a^c f(X)\,\mathrm{d}X = 1 \tag{1}$$

For values of X between A and C, the probably density function $f(X)$ of the triangular distribution is given by:

$$f(X) = \begin{cases} \dfrac{2(X-A)}{(C-A)(B-A)} & \text{if } A \leq X \leq B, \\ \dfrac{2(C-X)}{(C-A)(C-B)} & \text{if } B \leq X \leq C \end{cases} \tag{2}$$

where B is the 'best guess'; the mode of the distribution. Sampling 5000 times, the Monte Carlo empirically determines the mean and 95% confidence intervals (Fig. 3).

2.10. Best guess

A 'best guess' estimate could be found only for groundfish trawl (Fig. 4), as there were several independent time series of discards available for that fishery.

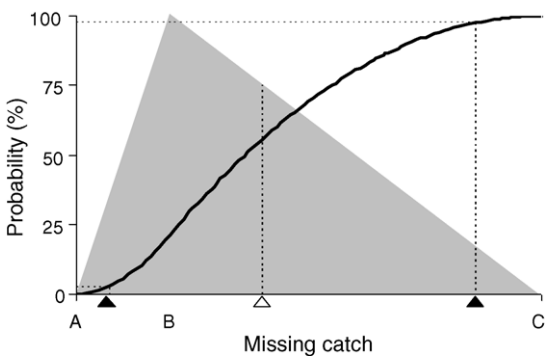

Fig. 3. Cumulative probability distribution of missing catch (line). (A) lower bound; (B) "best guess"; (C) upper bound. Triangle distribution provided for comparison (shaded area); the height of the triangle is $2/C-A$. Monte Carlo empirically estimates the mean (open arrow) and 95% confidence limits (closed arrows). The example distribution shows the error assumption used for most fisheries, where 20% of the error falls to the left of the mode.

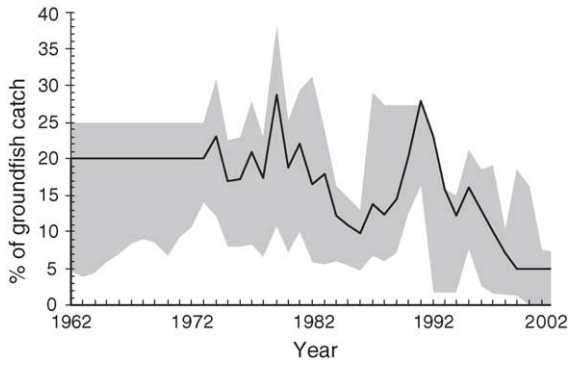

Fig. 4. Likely range of groundfish discards. Shaded area shows full range of estimates available in the literature; black line shows 'best guess'.

The lower and upper bounds and the best guess do not represent contiguous data series; they are each composites of three or more data series. The lower and upper bounds were set respectively by the largest and smallest estimate of discards found in the literature for a given year. The 'best guess' was based on an intermediate estimate, if available.

In our calculations, the 'best guess' estimate for groundfish trawl was extended to other groundfish fleets in proportion to their respective (independently scored) absolute ranges. We therefore assumed that the annual discard trend for trawl could be applied to other groundfish fleets, and that years of high discarding in trawl would correspond to years of high discarding in hook and line and the recreational fishery.

Sufficient data was not available to provide a 'best guess' estimate for salmon discards, salmon illegal catch, or groundfish illegal catch. Therefore, the 'best guess' for these IUU elements was said to be 20% of the total range offered by their lower and upper bounds (i.e. the Monte Carlo draws from an error distribution skewed to the right; 20% of the error falls to the left of the mode, see Fig. 3). We therefore assumed that if the true quantity of missing catch is less than our best guess, then our guess will not be too far off, but if the true value is greater than our best guess, it is liable to be much greater. In other words, we are certain that there is at least an appreciable amount of missing catch. For unreported catch in the salmon recreational fleet, the 'best guess' was assumed to fall in the middle of the possible range, so that the Monte Carlo drew from a symmetrical distribution. Considering the potential magnitude of missing catch, we did not feel that the 'best guess' ought to be conservative.

3. Results

3.1. Determining absolute quantities of missing catch

Assigning absolute quantities to the incentive ratings is the most subjective component in this methodology—and one that will require additional refinement and review by experts if such an analysis is to contribute to management. Based on the range of discarding, illegal and unreported catch rates described by the anchor points, Table 5 was constructed to define the absolute quantity of missing catch for each incentive rating. The three IUU categories, discard, illegal and unreported catch, are treated independently.

Numbers listed in bold are anchor points based on one or more sources from the literature (values are taken from representative periods in Table 3). Numbers listed in italics are scaled based on these available estimates, such that the influence 'medium–high' rep-

Table 5
Absolute ranges of IUU catch rate for each incentive rating (percent IUU per weight of target catch)

IUU category	Influences	Scaling factor	Salmon (%)	Groundfish (%)
Discard	H	1.0	**2.7**	**24.8**
	M/H	0.8	*2.2*	*19.8*
	M	0.6	*1.6*	*14.9*
	L/M	0.4	*1.1*	*9.9*
	L	0.2	*0.5*	*5.0*
Illegal	H	1.0	*0.19*	*0.19*
	M/H	0.8	**0.15**	*0.15*
	M	0.6	*0.11*	*0.11*
	L/M	0.4	*0.08*	*0.08*
	L	0.2	*0.04*	**0.04**
Unreported	H	1.0	**246**	–
	M/H	0.8	*197*	–
	M	0.6	*148*	–
	L/M	0.4	*98*	–
	L	0.2	*49*	–

Bold numbers are from literature (rated low to high based on time series), numbers in italics are scaled based on bold number.

resents 80% of the upper bound, ‘medium’ is 60%, ‘low–medium’ is 40%, and ‘low’ is 20%.

Treating all salmon gear types the same, we assumed that each sector will conform to this range, defined by an upper bound of 2.7% discards per weight of total catch, and 0.19% illegal catches per weight of total catch. Similarly, we assumed that the unknown catch occurring in the groundfish fishery is comparable among sectors, and contained within an upper bound of 24.8% for discards, and 0.19% for illegal catch. The unreported catch range (upper bound 246%) refers to the recreational salmon sector only. However, the majority of ‘unreported’ catch for commercial salmon and groundfish fleets is probably considered within the calculation of discards. We do expect some degree of overlap between categories.

Table 6 shows the product of the subjective portion of the methodology, a minimum and maximum estimate of missing catch for each period and gear type. Missing catch is presented as a percentage of known catch for each fleet. These values were converted into absolute quantities using catch statistics in Table 4 for input into the Monte Carlo.

Table 7 shows the output of the Monte Carlo, the mean estimate of missing catch with 95% confidence limits in each category of IUU, by period and gear type.

Fig. 5 shows the estimated catch missing from official statistics for all BC salmon and groundfish fisheries. Discards are low in the pelagic salmon fishery compared to the demersal fleet, but discards for both salmon and groundfish are currently on the decline. Illegal catch is small in both fisheries compared to total IUU extractions, although our estimate is admittedly conservative. Missing catch from the salmon recreational fishery (called ‘unreported’) is not shown, but it comprises the large majority of total salmon IUU (lower-left graph).

Fig. 6 shows total estimated extractions from BC salmon and groundfish fisheries. The black area shows the official reported catch and the grey area shows the upper limit of missing catch at 95% confidence. IUU catch is currently on the decline for both salmon and groundfish sectors in proportion to recorded weight and in absolute terms. In 2000, catch missing from official salmon statistics appears negligible overall, but catch missing from groundfish records may be a concern.

Table 6
Monte Carlo input: IUU catch range (% of fleet catch by weight)

IUU category	Target Sp.	Fleet	Period									
			1950–1954	1955–1959	1960–1964	1965–1969	1970–1974	1975–1979	1980–1984	1985–1989	1990–1994	1995–1999	2000–2003
Discards	Salmon	Gillnet	2.2–2.7	2.2–2.7	2.2–2.7	2.2–2.7	2.2–2.7	2.2–2.7	2.2–2.7	2.2–2.7	1.6–2.2	1.1–1.6	0.5–1.1
		Trailer	2.2–2.7	2.2–2.7	2.2–2.7	2.2–2.7	2.2–2.7	2.2–2.7	2.2–2.7	2.2–2.7	1.6–2.2	1.1–1.6	0.5–1.1
		Seine	2.2–2.7	2.2–2.7	2.2–2.7	2.2–2.7	1.6–2.2	2.2–2.7	2.2–2.7	2.2–2.7	1.6–2.2	1.1–1.6	0.5–1.1
		Recreational	1.6–2.2	2.2–2.7	2.2–2.7	2.2–2.7	2.2–2.7	2.2–2.7	2.2–2.7	2.2–2.7	2.2–2.7	1.1–1.6	0.5–1.1
	Groundfish	Trawl	0–5.0	5.0–9.9	5.0–9.9	14.9–19.8	14.9–19.8	14.9–19.8	14.9–19.8	9.9–14.9	14.9–19.8	5.0–9.9	5.0–9.9
		Hook and line	0–5.0	5.0–9.9	5.0–9.9	5.0–9.9	9.9–14.9	9.9–14.9	9.9–14.9	9.9–14.9	14.9–19.8	14.9–19.8	14.9–19.8
		Recreational	5.0–9.6	14.9–19.8	14.9–19.8	14.9–19.8	9.9–14.9	14.9—19.8	14.9–19.8	14.9–19.8	19.8–24.8	9.9–14.9	5.0–9.9
Illegal	Salmon	All	0.15–0.19	0.15–0.19	0.15–0.19	0.15–0.19	0.15–0.19	0.15–0.19	0.15–0.19	0.15–0.19	0.11–0.15	0.04–0.08	0–0.04
	Groundfish	All	0.15–0.19	0.15–0.19	0.15–0.19	0.15–0.19	0.15–0.19	0.15–0.19	0.15–0.19	0.15–0.19	0.11–0.15	0–0.04	0–0.04
Unreported	Salmon	Recreational	197–246	197–246	197–246	197–246	197–246	197–246	197–246	197–246	197–246	49–98	0–49

Table 7
Monte Carlo output: mean IUU catch with 95% confidence intervals (tonnes)

IUU category	Target Sp.	Fleet	95% CI	Period										
				1950–1954	1955–1959	1960–1964	1965–1969	1970–1974	1975–1979	1980–1984	1985–1989	1990–1994	1995–1999	2000–2003
Discards	Salmon	Gillnet	Upper	895	681	629	638	751	444	393	565	489	177	107
			Mean	818	621	574	583	685	404	359	515	426	151	79
			Lower	763	579	535	542	638	377	335	479	379	132	58
		Trailer	Upper	307	295	301	432	453	453	486	592	422	106	21
			Mean	281	269	275	395	413	413	443	540	366	90	15
			Lower	262	251	256	368	385	386	412	504	325	79	11
		Seine	Upper	955	650	557	525	565	635	823	1232	784	282	163
			Mean	874	595	508	479	491	580	752	1127	680	240	119
			Lower	814	554	473	446	438	541	700	1049	607	210	87
		Recreational	Upper	87	81	149	159	191	153	135	188	177	46	21
			Mean	76	74	136	146	174	140	123	172	161	39	15
			Lower	68	69	126	136	162	130	115	160	150	34	11
Groundfish		Trawl	Upper	849	1589	4020	4010	2943	4290	8297	6997	13542	8044	7472
			Mean	397	1197	3643	3631	2658	3927	7358	5707	12233	6709	5633
			Lower	70	919	3234	3225	2363	3440	6642	4904	10861	4815	4314
		Hook and line	Upper	98	210	254	526	288	253	329	592	1666	1986	1907
			Mean	46	159	192	465	241	212	275	496	1471	1754	1685
			Lower	8	122	149	421	207	183	238	427	1329	1587	1523
		Recreational	Upper	–	–	–	–	–	–	257	268	164	127	77
			Mean	–	–	–	–	–	–	227	235	148	107	55
			Lower	–	–	–	–	–	–	205	213	137	92	42
Illegal	Salmon	All	Upper	159	120	115	123	147	118	129	181	125	30	11
			Mean	143	108	103	111	132	106	116	163	109	22	5
			Lower	132	99	95	102	122	98	107	150	98	17	1
	Groundfish		Upper	36	36	43	43	32	44	84	99	114	32	32
			Mean	33	32	39	39	29	40	76	89	100	15	15
			Lower	30	30	36	36	26	37	70	83	89	3	3
Unreported	Salmon	Recreational	Upper	9886	7432	13,599	14,592	17,437	14,015	12,315	17,181	16,173	2778	909
			Mean	9107	6845	12,510	13,434	16,048	12,887	11,334	15,818	14,898	2207	513
			Lower	8327	6256	11,422	12,290	14,658	11,770	10,362	14,435	13,611	1629	114

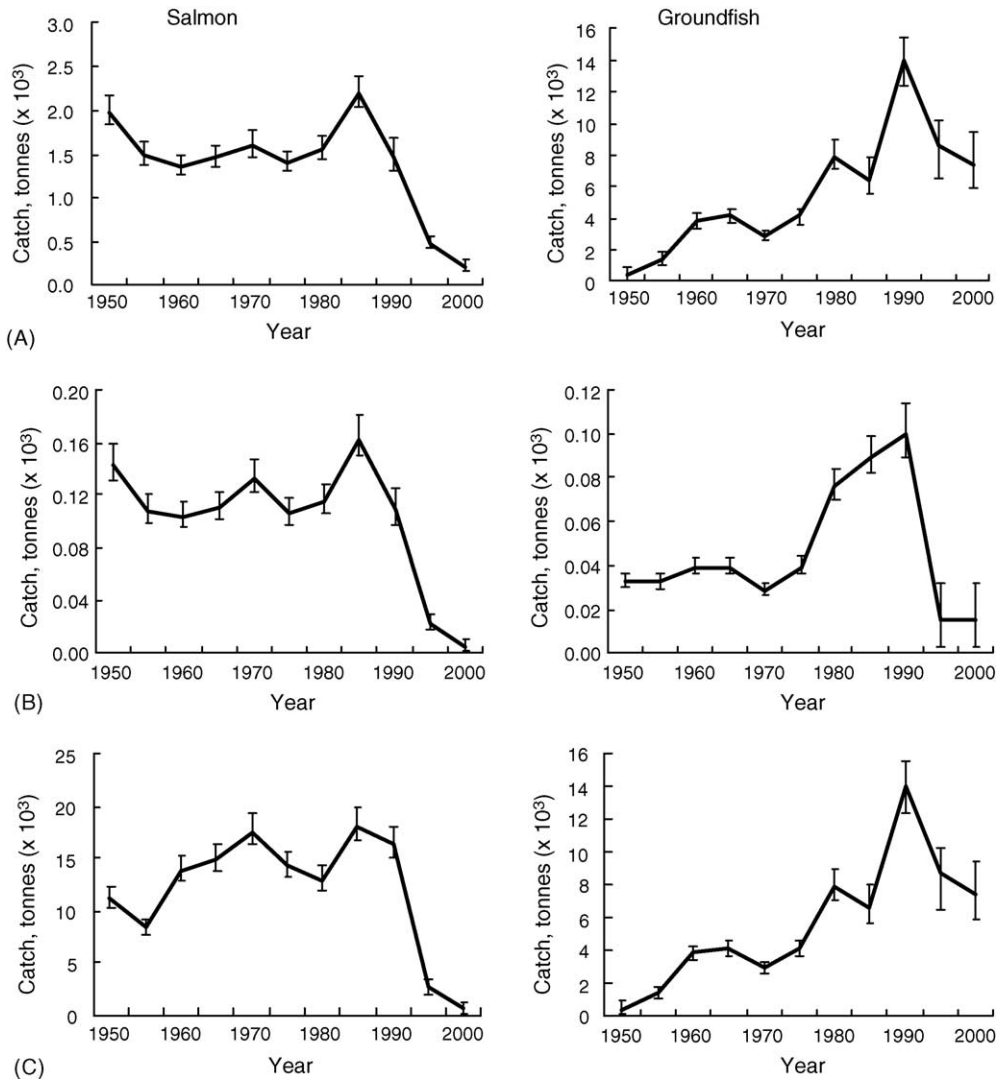

Fig. 5. Estimates of missing catch for salmon and groundfish fisheries. Line shows the mean of 5000 Monte Carlo samples with 95% confidence intervals. (A) Discards; (B) illegal catch; (C) total IUU catch. Salmon (C) also includes unreported recreational catch.

4. Discussion

4.1. Discards

Discards in the salmon fleet appear small in comparison to the reported catch. The highest values in the literature suggest they are around 5–6% of total landings. Our analysis suggested that discards hovered around 2.2% until the mid 1980's, when they began to drop to current levels of less than 1%. Major political changes in the fishing industry would have contributed to this reduction, but the 1980s also saw technical changes in the way people fish for salmon. Gear modifications were introduced, like weedlines in gillnets and brailing boards in the seine fishery, and used in conjunction with new techniques to improve selectivity and reduce interception of non-target species. Ongoing experiments to improve gear selectivity, and

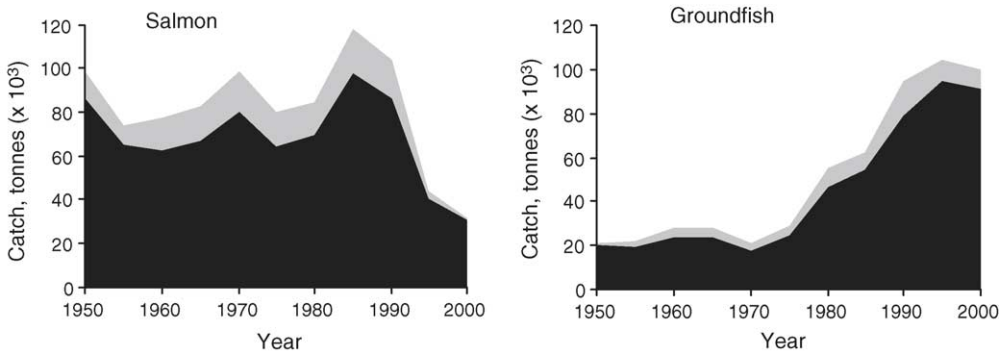

Fig. 6. Total estimated extractions in BC salmon and groundfish fisheries. Black area shows official reported catch; grey area shows upper estimate of IUU catch at the 95% confidence limit.

revival of effective traditional techniques in terminal fisheries (e.g. weirs, fish wheels) may be expected to reduce discarding even further in the future. Generally, the nature of pelagic salmon fisheries allows fishers to avoid bycatch more easily than the demersal fleet.

After shrimp trawl, the most unselective fisheries in BC are for groundfish. At its worst (from 1980 to 1985), we estimated that the hook and line fleet discarded a weight of fish equivalent to 22.6% of its recorded catch, and the trawl fleet (at its worst between 1975 and 1980) discarded about 17.8%. Unlike the fisheries for Pacific salmon, groundfish operations have seen a steady increase in landings since the 1950s. As effort increases, so does incidental catch. However, in recent years, bycatch reduction initiatives have seen some success. Mesh size regulations, exclusion panels, grates, unhooking techniques and species-selective baits have been used to reduce incidental capture. Thanks to these modifications, we estimated that discards are now at their lowest levels in 20 years, despite a three-fold increase in groundfish landings.

4.2. Illegal catch

Illegal catch probably constitutes a very small portion of IUU in BC fisheries. The incentives and opportunities to poach in both salmon and groundfish fleets remained stable, according to our review, until about the 1990s. Observer programs began in this period for several fisheries, but more importantly, the significant quantity of illegal catch that had been occurring in an unofficial commercial aboriginal fishery, was made legitimate by political changes (e.g. sparrow decision, pilot sales program) (Wappel, 2003). BC salmon stocks are not what they once were however, and we may expect to see an increase in illegal catch in the coming years as restoration efforts restrict lawful fishing opportunities. This is certainly the case with northern abalone (Haliotis kamtschatkana), in fact rampant poaching has been blamed for preventing its recovery in BC (DCI, 1999).

4.3. Unreported

In recent decades, the recreational sector accounted for only 8% of salmon landings throughout the province (Table 4). Although the gross quantity of unreported salmon catch in the sport fishery may be small compared to commercial extractions, there exists a wide-spread (and probably well-founded) perception among commercial fishers that the recreational sector is not subject to the same strict accounting as the rest of the fleet (C. Ainsworth, pers. obs.). Data entry is not standardized, reporting is often voluntary, and large data gaps exist in the catch record—these factors combined make our estimate of unreported catch significant. Our results suggest that unreported sport salmon catches may have exceeded 220% of the official statistics until the mid-1990s. We estimate that since that time unreported catch has been reduced by almost an order of magnitude relative to recorded landings. As salmon stocks continue to decline, particularly troubled chinook populations that have been the mainstay

of anglers, we expect the absolute quantity of missing catch to fall.

This analysis of unreported catch could be extended to include commercial salmon fisheries using a back-calculation technique employed by other authors. Patterson et al. (1990) estimated the unreported catch of the Ecuadorian tropical chub mackerel (*Scomber japonicus*) based on the output of fishmeal factories, and Castillo and Mendo (1987) estimated catch for Peruvian anchovy (*Engraulis ringens*) using the same method. In BC, packing records extending back to the 1950s are available from industry (BCSMC, 2004), and could be compared with official catch statistics to provide an estimate of unreported catch throughout the years.

Although this study has not attempted to quantify unreported recreational catch in the groundfish sector, it is worth noting that there is a discrepancy of almost 20-fold between the DFO Pacific Region creel estimates of recreational rockfish landings (22 tonnes in 2000), and the DFO Statistical Services Branch estimate (400 tonnes) (K. Brickley, DFO Statistical Services Branch, Ottawa, pers. commun.). Although the gross amount is small compared to commercial rockfish landings, unreported catch could be an important factor in this fishery considering the vulnerability of rockfish stocks to overexploitation, and the current drive to reduce landings. On the other hand, recreational catch of halibut seems to be well recorded. Catch records between Washington State (USA) data and DFO national survey results agree within 3% for the number of fish landed in Canadian waters.

4.4. Limitations to this methodology

The nature of IUU catch demands a subjective method for quantification. The most approximate step in this methodology, and the one most likely to arouse scrutiny, comes when we assign an absolute range of missing catch for each low, medium or high rank in the relative incentives table. Certainly, the approximation could benefit from further discussion with experts in BC fisheries, particularly with experts involved in each gear class. With their contribution, we could apply the general trend suggested by the influence table more relevantly to each gear type.

Also, it is difficult under this methodology to estimate the species-specific composition of IUU catch. In this report, we have aggregated all species together by weight, to produce an estimate of IUU catch per tonne of fish landed. In fact, anchor points recorded cannot distinguish even target species discards (e.g. juveniles) from non-target fish or invertebrates. It would be possible to refine the estimate into species-specific categories of discards and illegal catch, but each series would require its own anchor points.

The estimation procedure presented here can be easily updated as more and better information becomes available. The analysis could be expanded to include additional anchor points, and improved ‘best guess’ estimates to define the distribution of likely error. There is still unused potential in the influences table; however, the availability of anchor points is limiting.

4.5. Global IUU issues

This method provides a simple and quick way to quantify IUU catch, and it can be done under data-limited conditions. It may therefore prove to be a useful tool for addressing the IUU problem on a global scale. So far, the methodology has been applied to 10 countries or jurisdictions worldwide, and the estimates of missing catch are being integrated into the Sea Around Us Project (SAUP) Global IUU Database (R. Watson, T. Pitcher, UBC Fisheries Centre, Vancouver, pers. commun.). The database also currently contains 21,591 individual entries; quantitative and semi-quantitative reports of missing catch indexed by year, country, gear type, taxon and other fields. The collected information should make it easier for future authors to apply this methodology to other parts of the world, while the new technique will offer a rigorous way to incorporate subjective information and expert knowledge into the database.

5. Conclusions

As fishing power increased from the 1950s to 1970s, IUU catch increased in proportion to recorded landings for the major fisheries in BC. During the 1970s, operational changes began to take effect that would counteract the improved catching ability of fishers, and regulate fisheries that were previously open access.

Exploitation increased throughout the 1980s, and the largest quantities of missing catch probably occurred in the early 1990s for most fleets. It was not until the mid 1990s when IUU catch began to fall in proportion to landings, but these days enforcement and monitoring are strict, and new regulations have likely reduced the amount of catch missing from official statistics.

From about the 1950s to the 1980s, we estimated that between 10,000 and 20,000 tonnes of catch went unrecorded every year in the BC salmon and groundfish fisheries. IUU catch increased throughout the 1980s, and by 1990, the amount was probably closer to 30,000 tonnes per year. That is equivalent to 18% of recorded landings. By 2000, we estimated that IUU catch had fallen to about 8000 tonnes per year, or 6.6% of landings. The influences table suggests that the downward trend has continued to the present for salmon fleets, due to better enforcement and data collection, but may have leveled off for the groundfish fleets. Continued fishery closures and routine reductions in the legal capture size restrict the amount of catch that can be landed—encouraging discards. Despite compulsory observer programs, we suggest that wide scale implementation of the quota system in groundfish fisheries has also increased the motivation to high grade.

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