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Unreported bycatch in the New Zealand West Coast South Island hoki fishery

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ABSTRACT

There are recognised benefits to managing fisheries by individual transferable quotas (ITQs), but ITQs may increase incentives to discard fish.

Trawl data from government-observed trawlers in the New Zealand hoki fishery were used to predict catches of unobserved vessels. These predictions were compared with the catches unobserved vessels reported. Unobserved vessels' reported catches were significantly different to observed vessels' catches. There was clear evidence of misreporting in the hoki fishery. Misreporting deprives stakeholders of rentals, distorts catch statistics, and threatens the integrity of ITQ systems. If reporting is similarly biased in other fisheries, the issue cannot be safely ignored.

1. Introduction

Fisheries management by individual transferable quotas (ITQs) is promoted as a means of achieving allocative efficiency, ending overcapitalisation, improving product quality, and promoting safety at sea [1]. These benefits have been demonstrably achieved in New Zealand fisheries [2]. In 1986, New Zealand became one of the first countries to implement an ITQ system [3].

No management system is perfect. ITQs have some inherent problems. In most circumstances, implementing ITQs increases incentives to discard[1] or highgrade fish [4], especially where limits are imposed on landings rather than on catches [5,6]. Much theoretical work in this area is predicated on an assumption that enforcement is sufficiently effective to deter unreported landings of over-quota fish. Branch et al. [7] reported that discards[2] declined after introduction of ITQs to the British Columbia groundfish fishery. However, this fishery enjoyed full-time at-sea observer coverage, a rare situation.

Most theoretical analyses of discarding are confined to the special case where there are only two categories of fish [8]. It is generally recognised that additional incentives to discard arise in multispecies fisheries, due to imbalances between catches and quotas at the level of the firm [9–11]. The decision to discard is ultimately made by the individual with the fish in hand. The incentives of the firm and the individual crew member may not always be aligned. This does not appear to have been considered in the theoretical literature to date.

Where enforcement is not sufficiently effective to ensure over-quota fish are reported, the incentive is for the firm to misreport. Unreported discarding can be seen as a special case of misreporting. Undeclared landings or trans-shipments, under-reporting of landing weights and mislabelling of species may be profitable alternatives.

The largest fishery in New Zealand waters is for hoki, *Macruronus novaezelandiae*. Nearly all hoki are taken by trawling. This results in incidental capture of a number of fish species [12]. Some of these bycatch species have intrinsic commercial value; some do not. Some are managed by individual transferable quotas, and others have no catch limit. Regardless of their value and management status, NZ legislation requires that all fish caught be reported and that all ITQ species be landed. Exceptions to the second rule apply to some species likely to survive return to the sea, but catches of these species must nevertheless be reported.

A proportion of vessels involved in the hoki fishery carry government observers. If misreporting is occurring, vessels with observers would be expected to report and land a greater quantity and diversity of bycatch than unobserved vessels. Exceptions may

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[2] Following Branch et al. [7], in this paper we use the term "discards" to mean fish caught but returned to the sea; "landings" to mean retained catch; "catch" as all fish caught; "bycatch" as all fish caught in a tow excepting those of the target species, and "highgrading" as the practice of preferentially discarding less valuable (generally smaller) fish of the same species in order to retain a higher proportion of more valuable fish.

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occur for bycatch species not managed by ITQ, where the most profitable option might be to report ITQ species bycatch as non-ITQ species and thus avoid the cost of acquiring quota. There may be other incentives to misreport than those already mentioned. Some are discussed later.

The present study used data from a discrete part of the NZ hoki fishery to test whether or not bycatch was accurately reported. Data from the observed tows were used to predict catch of the unobserved vessels. These predictions were compared with the catch reported in the unobserved vessels' logbooks to determine the quantity of fish misreported.

2. The study fishery

The hoki fishery is the largest and the most valuable fishery in the New Zealand Exclusive Economic Zone. Since 1989, the hoki population has been assessed as two stocks, eastern and western [13]. In 2005, the total allowable catch (TAC) was 101,000 t. Hoki are widely distributed. Historically, the main fishing ground has been off the west coast of the South Island (WCSI) [14]. Hoki from the western stock migrate there each winter to spawn. Spawning aggregations begin to concentrate in June, in depths of 300–700 m around the Hokitika Canyon, and disperse again by the end of September. Catch in this fishery is now limited to 40,000 t/year, and substantial fisheries have developed elsewhere.

Despite this dispersal of effort, there is still an intense WCSI trawl fishery during the spawning season. Most fish are taken by large factory trawlers. In 2005, there were 36 factory trawlers fishing an area measuring about 130 by 15 nautical miles. Twenty-six were foreign owned and crewed vessels chartered by New Zealand companies. Vessels ranged in length from 51 to 105 m. Vessels over 46 m in length are prohibited from fishing within 25 nautical miles of the coast. In this study, we looked exclusively at the activities of factory trawlers fishing for hoki outside the 25 nautical mile exclusion zone between June and September 2005. These vessels did not fish the densest aggregations of spawning hoki at the head of the Hokitika Canyon.

When fishing is poor in the outer part of the Hokitika Canyon, the factory fleet tends to concentrate along the continental slope to the north, taking fish moving to and from the spawning ground. Vignaux [15] describes the spatial structure of the fishery in detail.

Factory trawlers operating in the WCSI hoki fishery normally stay at sea for 4–8 weeks, and land their catch at New Zealand ports. They usually make fewer than three trips during the winter spawning season. They may not target hoki exclusively during a trip, especially at the beginning and end of the season when hoki or quota availability may be limited. Other species commonly targeted are jack mackerels, hake, silver warehou, and barracouta. The vessels use either mid-water or bottom trawl nets with mesh size of 100–115 mm, in depths of 300–700 m. Vessels commonly carry both mid-water and bottom trawling gear. Fishing continues around the clock. It is common for vessels equipped with both types of gear to bottom trawl during daylight and switch to mid-water gear at night. Mid-water trawls are normally towed very close to the seabed and may contact it. Some tows are taken higher in the water column, especially when dense spawning aggregations are being targeted. These tows are identifiable from vessel logbooks.

Regardless of whether vessels are equipped for filleting at sea, most bycatch is landed as fishmeal, frozen blocks of whole fish, or frozen blocks of headed and gutted or "dressed" product. Ling and hake are often filleted at sea.

3. Data sources

3.1. Vessel logbooks

The master of each trawler is required to complete trawl catch effort and processing returns (TCEPR) forms, in which they must record information about each tow and about daily processing. On landing, the master must also complete a catch landing return (CLR), containing summary information about all fish taken on the trip. Both of these returns must be provided to the Ministry of Fisheries.

The present study considered 879 TCEPR returns describing 2170 unobserved tows. CLR returns were only used to check aggregate catches reported on the TCEPRs.

The TCEPR provides effort data for each tow, including

vessel,
date,
time at start and end,
position at start and end,
groundline depth at start and end,
seabed depth at start and end,
fishing speed,
headline height and wingspread,
gear type,
target species,
total catch (kg), and
estimated catch by species (kg).

Estimated catches are recorded for the five most abundant species in each tow. The estimates are supposed to be visual, but actual practice seems to vary from vessel to vessel. "Total catch" and the estimated hoki catch were used as possible predictors of bycatch. Other estimated catch values were not used.

The "processing" section of the TCEPR is a summary of all catch processed by the factory during the preceding 24 h. This may or may not be the fish from the tows recorded in the "effort" section of the same form, as processing for the last tow of the day may not have been completed by midnight. In theory, processing data cover all species caught and provide an aggregate weight for each. The process of calculating aggregate weights differs between vessels, species, and processed states.

3.2. Observer data

Observers were assigned in pairs to 13 factory vessels. They observed 14 trips, collecting data from each tow. Observer assignment was not random. Health and safety concerns precluded assignment to several vessels. Observer availability restricted the number of vessels that could be observed simultaneously. Information collected about each observed tow included

vessel,
date,
time at start and end,
position at start and end,
groundline depth at start and end,
seabed depth at start and end,
fishing speed,
headline height and wingspread,
gear type,
target species,
total catch (kg), and
estimated catch by species (kg).

Observers used various standard methods for estimating catch weights, from direct weighing to estimation based on volume. In general, the precision of these estimates will be inversely proportional to the catch weight, but all the methods should be free of systematic bias. The observers also collected net plans and measured net meshes.

3.3. Fishery officer surveillance

During the season, fishery officers boarded nearly all the unobserved vessels. They collected landing data and net plans, measured net meshes, and noted the nationality of the vessel's officers. Surveillance flights during the season detected no direct evidence of discarding at sea.

3.4. Vessel registration data

All fishing vessels operating in NZ waters are registered by the Ministry of Fisheries. The vessel register was used to determine registered length and maximum freezer hold capacity for each vessel studied, and whether or not each was equipped for filleting and/or fishmeal production. The register records each vessel's nationality, but because some were registered under flags of convenience the present study describes vessel nationality by the nationality of the officers.

3.5. Quota availability and prices

In New Zealand, ITQs are tradable "shares" in the fishery. ITQs generate annual catch entitlements (ACE), the actual weight of fish allowed to be taken during a fishing year. ACE may be traded separately from quota shares, but expire at the end of the fishing year. Balancing of reported catch against quota occurs monthly, 20–28 days in arrears. Each firm's holdings of ACE for and catch of particular fishstocks are displayed on a public register. It is not possible to determine if a firm had sufficient ACE to cover catch at the actual time of fishing, but their end-of-year position can indicate incentives to discard due to insufficient ACE holdings existed at some time during the fishing year. Each firm's year-end position was categorised as follows:

- undercaught (reported catch was $>10\%$ under ACE held),
- balanced (reported catch was within $\pm 10\%$ of ACE held), and
- overcaught (reported catch was $>10\%$ over ACE held).

ACE prices (NZ&dollar/kg) were derived from trading records on the ACE register.

3.6. Value of fish

Average values of species managed under the ITQ system and some non-ITQ species were determined from gazetted "port prices." The Ministry of Fisheries derives these average annual port prices from prices offered by New Zealand licensed fish receivers. They may not represent the true value of a species to an individual firm. Different firms have different marketing and market access arrangements. For example, fish landed by Korean vessels is treated as "domestic fish" in Korea. The same fish caught from a New Zealand vessel would incur tariffs. New Zealand port prices are therefore rough guides to the actual values.

4. Methods

4.1. Variables important in explaining bycatch

Bycatch species that occurred in fewer than 40 of the 978 observed hoki tows were not considered. For each of the 41 remaining species, the percentage occurrence in observed tows, the average catch of observed tows, the port price, ACE price of ITQ species and whether the stock as a whole was undercaught, overcaught or in balance at end-of-year were calculated.

Duration (end time–start time); differential depth (seabed depth–groundrope depth); swept area (wingspread $\times$ towing speed $\times$ duration, calculated as hectares); and filtered volume (swept area $\times$ headline height, calculated as km^3) were calculated for each observed tow. These calculated variables were plotted against catch per tow in a series of scatterplots, along with

date,
start time,
starting latitude,
seabed depth at start of tow,
fishing speed,
headline height,
total catch, and
hoki catch.

Starting longitude was ignored. Because the fishery is effectively a ribbon of seabed running SW to NE, tow latitude and longitude are highly correlated.

Dichotomies were derived from the continuous variables "Latitude", "Seabed depth" "Start time", and "Differential depth", as it was evident that the responses to these variables were invariably step functions.

No species showed a linear response to latitude. "Latitude" was converted to a dichotomous variable which referred to the Hokitika Canyon. All tows south of 42°45′ were considered to be in the Canyon. "Canyon" proved an important predictor for bycatch species.

"Date", "Start time", "Seabed depth", and "Differential depth" were also converted into dichotomies, respectively, "Season", "Night", "Depth range", and "DDepth". Cutoffs were based on interpretation of scatterplots and varied between species.

Variables which appeared to influence the catch of the species under consideration were used to develop a mixed model using SAS Proc MIXED [16], with "vessel" included as a random effect.

Scatterplots, model results, and prior knowledge of species' biology and seasonality were used to derive post-sampling stratification schemes for each species. The minimum stratum size accepted was 40 tows, excepting instances where small strata would logically contain zero catch, e.g. when all tows in a stratum would be below the maximum depth recorded for that species.

Defining different strata for each bycatch species is uncommon, probably because of the computation required, but not unprecedented [17]. The purpose of stratification is to divide a heterogeneous population into fairly homogeneous parts, and thereby ensure differences between the strata means are removed from the sampling error of the overall estimate [18]. Bycatch species may respond differently to environmental and geographical variables. A uniform stratification scheme is therefore unlikely achieve homogeneity within all strata for all species and would generate unnecessarily high confidence intervals. The effectiveness of the stratification for each species was determined by contrasting the total variance, $(\text{actual}-\text{overall mean catch})^2$ with the sum of the stratum variances $(\text{actual catch}-\text{mean catch for that stratum})^2$. This contrast was used to choose the most effective alternative in cases where several different stratification schemes were feasible.

4.2. Estimation of catch by the unobserved fleet

Point estimation of the bycatch (B) of any species taken by the unobserved vessels in a fishery requires extrapolation from the mean catch rates (C) of the observed vessels, using some appropriate measure of effort (E) as a scalar, i.e. $B = E \times C$.

The appropriate measure of effort depends on the bycatch species involved. Possible candidates are tow, tow duration, swept area, filtered volume, and weight of the target species caught. The last is appropriate only for species known to be intimately associated with the target species. Tow duration, swept area and filtered volume are related. All seem intuitively attractive, though complex relationships between tow duration and catch are known to occur in other fisheries [19,20]. All these potential units of effort were considered during exploratory data analysis. For nearly all species, "tow" was allocated as the unit of effort. The alternatives offered little improvement. Mesh size was ignored, as all vessels in the fleet used mesh of similar dimensions.

Interval estimation of bycatch of any species taken by unobserved vessels requires an estimate of population variance. This can be obtained either by reference to a standard statistical distribution, if one can be found to fit the data, or by resampling from the observer data. Bycatch data for most species are characterised by large proportions of zeroes and occasional large catches. Attempts have been made to fit Poisson, negative binomial and negative binomial with added zero distributions to these data, with little success [21,22]. Resampling from observer data is computationally more intensive but inherently non-parametric, and has been widely applied in recent years [23]. For the present study, the preferred option was resampling stratified according to the variables described in the previous section.

Vessel "effort" data were used to determine the number of tows each vessel made in each stratum during each trip. A point estimate of bycatch for each species was calculated by multiplying the number of tows in each stratum by the average catch of the observed tows in that stratum. Days on which one or more tows targeted species other than hoki were removed from the analysis. Of 2413 unobserved tows targeting hoki during the season, 243 were not used.

Uncertainty in each point estimate was assessed using distributions obtained from bootstrap estimates comprising 1000 simulated fishing trips for each vessel. Each simulated trip comprised an appropriate number of observed tows, drawn from appropriate strata with replacement. Confidence limits were derived from the 95th and 99th percentiles of the bootstrap samples.

The point estimates and their associated confidence intervals were then compared with the aggregate catches reported by the unobserved vessels in the "processing" section of their TCEPR returns. Residual plots were used to check for any large anomalies or trends.

5. Results

Percentage occurrence of each bycatch species in the observed tows, average catch per tow (kg), port price, ACE price (if the species was managed by ITQ) and reported catch as a percentage of the TACC at the end of the fishing year are shown in Table 1. Port and ACE prices are in $NZ per tonne. The port price assumes the fisherman has ACE to cover the catch if required. Quoted port prices naturally reflect saleable grades. Small fish of any species may be rejected outright, and shore-based fishmeal plants often charge for processing reject fish. Percentage of TACC caught is reported catch as a percentage of the TACC at the end of the fishing year. Hoki is included for comparison.

The ling ACE price was actually higher than the port price. This can occur for stocks where the TACC is overcaught, as landings not covered by ACE attract a financial penalty called a "deemed value". For an overcaught stock, the marginal cost of ACE will be driven by the deemed value rather than the port price.

"Fishing speed" and "Total catch" were unrelated to bycatch of all species. Fishing speed data exhibited little contrast, being between 3.5 and 5 knots for nearly all trawls. Total catch might be expected to exhibit some effect due to variation in escapement [20,24] but no such effect was evident in the data considered during the present study.

Swept area, tow duration or filtered volume were included as covariates in all models, but generally contributed little to the results. This finding seems counter-intuitive, but complex relationships between tow duration and catch are known to occur in other fisheries. Somerton et al. [19] reported that catch per unit of swept area increased markedly for several species when they halved the duration of their research tows in the Bering Sea, but remained constant for red king crab. Godo et al. [20] also noted a complex relationship between catch per unit effort and duration in research tows, with increased CPUE in shorter tows. Both papers were concerned with tows of less than 1 h duration. In the present study, the apparent low contribution of these variables may reflect either the lack of contrast in the data, within tow variability or the dependence of tow duration on total catch weight.

As evident from Table 2, gear, time of day and whether fishing occurred inside or outside the Hokitika Canyon were frequently important. The mixed models often showed highly significant interactions between these factors. Interactions between gear type and time of day were expected, since many species are bathypelagic. Interactions between geographical position and gear type or time of day were unexpected, but may reflect the life histories of the species concerned. Patterns of incidental bycatch can identify population patterns that cannot be discerned in the targeted catch of a species [25]. The authors intend to discuss some patterns observed during this study in a separate paper. Season, depth, and differential depth were each important for some species.

Estimates of the total bycatch of species taken by the unobserved fleet whilst targeting hoki and the reported catch are shown in Tables 3 and 4. In these tables, "percentage" is reported catch as a percentage of estimated catch. All figures (other than the percentage) are scaled upward by 11% to account for the hoki tows ignored in the analysis because another species was also targeted on the same day. Hake, jack mackerel, barracouta, and silver warehou are omitted from Table 3. These species are intermittently targeted during the hoki season and vessels may strive to maximise their bycatch at other times, so they probably should not be regarded as "incidental" bycatch.

6. Discussion

6.1. Interpretation

The results suggest that the reported catch of unobserved vessels is different to the observed catch of similar vessels in the same fishery. This may mean the catches and fishing patterns of the observed vessels are not representative of the fleet as a whole; or that observers are better at identifying common fish in the catch than the vessels' crews.

Table 1
Frequent bycatch species in the 2005 WCSI hoki fishery.

Common name	Species	Percentage of tows	Catch rate (kg/tow)	Port price	ACE price	Percentage of TACC caught
Alfonsino	BYX	18	3.39	1680	635.40	16
Barracouta	BAR	34	228.86	190	51.20	101
Black seal shark	BSH	4	1.31	2050		
Bluenose	BNS	21	3.70	4100	669.10	57
Common roughy	RHY	21	2.67			
Conger eel	CON	11	1.09	500		
Deal fish	DEA	5	0.59			
Deep sea flathead	FHD	9	0.67			
Electric ray	ERA	6	0.33			
Frostfish	FRO	82	271.24	320	40.00	32
Gemfish	SKI	50	50.78	2420	650.00	209
Ghost shark	GSH	7	3.08	590	64.70	57
Hake	HAK	87	352.01	1820	1349.90	107
Hapuka & Bass	HPB	11	2.94	4560	1743.70	98
Hoki	HOK	100	7339.65	610	512.90	104
Jack mackerels	JMA	47	10.97	310	43.10	102
Javelin fish	JAV	82	35.96	1100		
Ling	LIN	92	287.03	1360	1648.60	110
Lookdown dory	LDO	24	6.02	700	175.00	64
Porbeagle shark	POS	4	5.50	470	51.70	28
Rat tail	RAT	43	8.89	200		
Rays Bream	RBM	21	5.65	830	112.80	26
Red cod	RCO	32	18.15	520	84.00	91
Redbait	RBT	64	14.76	500		
Ribaldo	RIB	7	2.80	1060	50.00	554
Rudderfish	RUD	7	1.01	500[a]		
Scabbardfish	BEN	39	15.34			
Scampi	SCI	7	0.13	18,660	8000.00	1
School shark	SCH	5	0.84	1770	1361.20	84
Sea perch	SPE	21	3.72	600	52.00	56
Shovelnose dogfish	SND	7	0.77	1000		
Silver dory	SDO	26	6.36	800		
Silver roughy	SRH	6	0.25			
Silver warehou	SWA	47	101.42	800	201.50	44
Silversides	SSI	10	0.66			
Slender smooth hound	SSH	7	5.04			
Smooth skate	SSK	9	4.68	390	135.90	55
Spiny dogfish	SPD	49	43.03	470	15.60	44
Squid	SQU	60	18.72	770	179.60	101
Stargazer	STA	12	7.63	950	542.80	98
Yellow boarfish	YBO	5	0.12	1140		

The variables used in stratifying the bycatch of each species are shown in Table 2.
[a] Port prices derived from the Melbourne fish market.

An alternative explanation is that the catches reported by unobserved vessels contain large elements of fiction. If the observed trips are representative of what is normally caught, the probability of obtaining the catches reported by the unobserved vessels is minuscule.

The proposition that vessels carrying observers report both a larger weight and a greater diversity of bycatch than do unobserved vessels is not new. Allen et al. [26] note that fishermen self-reporting discards in a Spanish fishery reported fewer species than observers. Discarding in this fishery was legal, so the omissions provided no financial benefit. Bromhead et al. [27] noted observed catch rates were higher than reported catch rates for 13 of 19 bycatch species in eastern Australian longline fisheries. Some of these species are common to the present study. Annala [2] observed that the ratio of bycatch to target catch landed by large NZ fishing vessels was generally higher when observers were on-board. These papers do not explicitly discuss causation.

Stanley [28] suggests that vessel logbooks will be deliberately falsified if fishermen believe the data will be used by enforcement agencies. Metuzals et al. [29] surveyed commercial fishermen in Newfoundland, and reported that 38% of fishermen surveyed admitted misreporting unobserved catches. Two respondents alleged observers had been offered substantial bribes. Other authors, e.g. Rijnsdorp et al. [30], have suggested that misreporting is greatly exacerbated by the introduction of quota management systems to mixed fisheries.

The present study provides clear evidence of quota-induced misreporting in the WCSI hoki fishery. This misreporting is not confined to quota species. The magnitude seems to partly depend on vessels' processing configurations. Table 5 below contrasts vessels with and without on-board meal plants, and shows reported catch as a percentage of expected catch for several groups and species of fish. "ITQ bycatch" is the catch of all ITQ species other than hoki, jack mackerels, hake, silver warehou, and barracouta. Again, the last four species are intermittently targeted during the hoki season, and vessels may strive to maximise their bycatch at other times. These species should not be regarded as "incidental" bycatch.

The difference between the vessels with and without on-board fishmeal plants suggests that species misreporting is widespread in the former group. In theory, whole fish sent to the meal plant are supposed to be accurately reported using data derived from samples taken at the input conveyor to the meal plant. In practice, the total quantity of whole fish sent to the meal plant has usually been back calculated from the quantity of fishmeal produced. This total was then apportioned across the various species after the fact. Since the total is fixed, omitting any ITQ species (or unwanted

Table 2
Stratification used for each bycatch species.

Common name	Species	Family	Basis for stratification
Alfonsino	*Beryx splendens & B. decadactylus*	Berycidae	C G S T
Barracouta	*Thyrsites atun*	Gempylidae	C G S T
Black seal shark	*Dalatias licha*	Dalatiidae	C G T
Bluenose	*Hyperoglyphe antarctica*	Centrolophidae	G T
Common roughy	*Paratrachichthys trailli*	Trachichthyidae	C G
Conger eel	*Conger* spp.	Congridae	C G T
Deal fish	*Trachipterus trachypterus*	Trachipteridae	C D G
Deep sea flathead	*Hoplichthys haswelli*	Hoplichthyidae	C G
Electric ray	*Torpedo fairchildi*	Torpedinidae	C G
Frostfish	*Lepidopus caudatus*	Trichiuridae	C G T
Gemfish	*Rexea* spp.	Gempylidae	C G S
Ghost shark	*Hydrolagus zealandiae*	Chimaeridae	C D G
Hake	*Merluccius australis*	Merluccidae	
Hapuka & Bass	*Polyprion* spp.	Percicthyidae	C G
Jack mackerels	*Trachurus* spp.	Carangidae	C G T
Javelin fish	*Lepidorhynchus denticulatus*	Macrouridae	G T
Ling	*Genypterus blacodes*	Ophidiidae	C G T
Lookdown dory	*Cyttus traversii*	Zeidae	C G T
Porbeagle shark	*Lamna nasus*	Lamnidae	C G
Rat tail	*Mixed Macrouridae*	Macrouridae	G T
Rays Bream	*Brama brama*	Bramidae	G S T
Red cod	*Pseudophycis bachus*	Moridae	G S T
Redbait	*Emmelichthys nitidus*	Emmelichthyidae	C G S
Ribaldo	*Mora möro*	Moridae	D G O T
Rudderfish	*Centrolophus niger*	Centrolophidae	C G T
Scabbardfish	*Benthodesmus* spp.	Trichiuridae	G S T
Scampi	*Metanephrops challengeri*	Nephropidae	C G T
School shark	*Galeorhinus galeus*	Triakidae	G T
Sea perch	*Helicolenus* spp.	Scorpaenidae	G O
Shovelnose dogfish	*Deania calcea*	Centrophoridae	C D G T
Silver dory	*Cyttus novaezealandiae*	Zeidae	C G S
Silver roughy	*Hoplostethus mediterraneus*	Trachichthyidae	G S T
Silver warehou	*Seriolella punctata*	Centrolophidae	C G S
Silversides	*Argentina elongate*	Argentinidae	C G T
Slender smooth hound	*Gollum attenuatus*	Pseudotriakidae	C D O S
Smooth skate	*Dipturus innominatus*	Rajidae	C G
Spiny dogfish	*Squalus acanthias*	Squalidae	G T
Squid	*Nototodarus* spp.	Ommastrephidae	D G S
Stargazer	*Kathetostoma* spp.	Uranoscopidae	C G
Yellow boarfish	*Pentaceros decacanthus*	Pentacerotidae	C D G T

G: gear type; T: time of day; S: time in season; D: depth; O: differential depth, C: inside or outside Hokitika Canyon.

Table 3
Estimated versus reported incidental bycatch of the unobserved fleet.

Common name	Estimated catch (t)	95% CI	Reported catch (t)	Percentage
Alfonsino	21	16–27	11	52
Bluenose	10	8–14	10	ns
Frostfish	447	357–554	263	59
Gemfish	225	206–243	260	115
Ghost shark	20	17–23	12	61
Hapuka & Bass	14	13–17	13	92
Ling	946	886–1007	796	84
Lookdown dory	30	27–32	50	167
Porbeagle shark	12	9–16	4	36
Rays Bream	8	7–10	8	ns
Red cod	78	70–85	47	60
Ribaldo	22	19–26	34	155
Scampi	0.7	0.6–0.8	0.3	50
School shark	3	3–4	2	67
Sea perch	21	21–23	14	68
Smooth skate	26	23–29	41	161
Spiny dogfish	179	163–195	140	78
Squid	98	89–107	125	128
Stargazer	42	39–47	43	ns

ITQ species only—barracouta, hake, jack mackerel, and silver warehou omitted. Percentage difference is calculated only where the reported catch is outside the 95% confidence interval.
ns: non-significant.

Table 4
Estimated versus reported catch of the unobserved fleet. Non-ITQ species only.

Common name	Estimated catch (t)	95% CI	Reported catch (t)	Percentage
Black seal shark	8	6–12	8	ns
Common roughy	7	5–8	11	157
Conger eel	7	6–8	14	217
Deal fish	0.9	0.7–1.2	2.2	250
Deep sea flathead	3	3–4	9	267
Electric ray	1.4	1.2–1.8	1.1	ns
Javelin fish	80	75–85	143	179
Rat tail	33	31–37	78	233
Redbait	42	34–50	165	392
Rudderfish	3.1	2.6–3.7	3.2	ns
Scabbardfish	22	19–26	121	545
Shovelnose dogfish	2.2	1.9–2.7	18	805
Silver dory	10	8–12	18	178
Silver roughy	1.0	0.9–1.1	0.2	22
Silversides	3	3–4	12	ns
Slender smooth hound	39	32–46	22	57
Yellow boarfish	0.7	0.6–0.8	0.8	ns

Percentage difference is calculated only where the reported catch is outside the 95% confidence interval.
ns: non-significant.

Table 5
Reported catch by unobserved fleet as a percentage of the expected catch derived from extrapolation of data from the observed vessels.

Species or group	Onboard fishmeal plant	
	No ($n = 17$)	Yes ($n = 15$)
ITQ bycatch	92	81
Non-ITQ bycatch	99	258

"ITQ bycatch" includes all species from Table 3 managed by ITQ excepting hoki, jack mackerel, silver warehou, barracouta, and hake. Non-ITQ bycatch is those species not managed by ITQ.

hoki) from the apportionment will automatically lead to inflation in the reported catch of non-ITQ species. Detection of misreported meal composition after the fact is difficult, so this form of species misreporting is relatively risk free. Quantitative polymerase chain reaction techniques could determine the proportions of each species in the fishmeal produced, but this has not yet been attempted.

Pascoe et al. [31] suggested that, in multispecies fisheries where only some species are subject to quota control, information on the output of non-ITQ species could be used to deduce the possible extent of misreporting. This suggestion is based on the assumptions that there are no incentives to misreport the non-ITQ catch and that there is some systematic correlation between non-ITQ and ITQ catches. The present study did not test the second assumption, but the data appear to refute the first.

Filleting vessels may have particular opportunities for disguising catch. The whole weight of fish landed is derived from the processed weight of the principal landed state multiplied by the official conversion factor. Minimising the weight of the principal landed state reduces the reported catch. Additional landed states do not contribute to reported catch, but may still be sold profitably. For example, heavy trimming of fillets will result in a reduction in the apparent reported catch. The trimmings can be used to produce standard fish block or fish mince.

In the WCSI hoki fishery ling is both a species filleted by suitably equipped vessels, and a genuine incidental bycatch. The contrast between the reported and expected catch of ling by fillet and limited processing vessels is shown in Table 6.

Table 6
Reported catch of ling by unobserved vessels as a percentage of expected catch.

Vessel type	Filleting at sea	
	No ($n = 23$)	Yes ($n = 9$)
Ling bycatch	89	78

Table 7
Reported catch of frostfish as a percentage of expected catch by vessel nationality.

Nationality	Percentage of frostfish
NZ	4
Korean	88
Old Soviet Bloc	85
Other	16

Inshore vessels target ling throughout the year. In a perfectly functioning market, the operators of these vessels would be bought out by those taking ling as inevitable bycatch. Misreporting ling catches may be a cheap alternative to buying ACE or quota.

Some misreporting seems to be strongly influenced by vessel nationality. An example is frostfish, as shown in Table 7 below.

Differences between nationalities are hard to interpret, since nationality, processing configuration and presence of meal plants are confounded. In the case of frostfish, the difference probably reflects market access. Korean vessels catching frostfish are able to sell it duty-free in the Korean market. Frostfish caught by NZ vessels faces a tariff barrier, and frostfish is not readily sold within Australasia. Bilateral negotiations on market access might provide incentives to land and report more of the catch of this species.

Some of the "missing" catch identified by the model described in the present study is probably discarded outright. Elasmobranchs, for example, are not likely to be eaten by the crew, and except in the form of shark fins are unlikely to be attractive to the domestic black market. The reported catch of elasmobranchs is lower than the expected catch for both fillet and limited processing vessels. However, discussion of the physical fate of most misreported fish can only be speculative.

6.2. Consequences

The impact of species misreporting is threefold.

Firstly, under-reporting ITQ species will either deprive quota owners of the full value of their ACE, or will deprive the state of deemed values that would otherwise be levied. It is difficult to estimate the foregone revenue, as ACE prices are driven by supply and demand.

Secondly, failure to report bycatch distorts catch statistics. Distorted catch statistics generate corresponding inaccuracies in biological stock assessments [32], and eventually flow through to suboptimal total allowable catch settings for the bycatch species. In some circumstances, this could be self-reinforcing. Unreported catch will generally result in an artificially high estimate of natural mortality (M). The age structure of a fishery reflects the total mortality rate. If the estimate of fishing mortality is low, M will be overestimated. An overestimate of M will tend to lower TACs and increase the incentives to discard. Rijnsdorp et al. [30] noted this possibility.

Thirdly, widespread misreporting of catches is a serious threat to the integrity of any ITQ system. Over-reporting non-ITQ catch could lead to inequitable allocation of quota should these species be brought under ITQ management in future, since allocations are based on past catch history. Under-reporting ITQ catch will lead to distorted market signals [33] biased stock assessments, and inappropriate management actions. Both over- and under-reporting will undermine the legitimacy of the management system, and in extreme cases under-reporting has the potential to result in fisheries collapse [34].

Solutions to the problem of misreporting in multispecies ITQ fisheries are not well developed. The only intervention known to be highly effective is full-time observer coverage. Superficially, this is an expensive alternative to fishers self-reporting their catches. During the 22 years that New Zealand fisheries have been managed by ITQ, there has been substantial investment in the administration and enforcement of catch reporting. The current system of shore-based monitoring of fisher-reported catch is complex and expensive. It is unclear whether it is sufficiently effective to guarantee the integrity of the Quota Management System. According to Metuzals et al. [29, p. 87] "if misreporting is ignored, and catch data are worthless, what you have is an uncontrolled fishery."

Can the reliability of fishers' catch reporting be improved? Gezelius [35] notes that compliance in general results from rational self-interest embedded in a normative system. In the case of the large vessels considered in this study, the "normative system" presumably operates at two levels: a "community" aboard the vessel; and a "community" of firms and quota owners involved in the fishery. Catch reports are usually provided to the government but are not available for inspection by either the vessel crew or the wider community, so community pressure on those misreporting catches is limited. Catch reports could be shared more freely. Gilman et al. [36] describe moves in this direction in US fisheries. There has been no comparable programme in New Zealand to date.

Several authors advocate modifying ITQ systems to reduce inherent incentives to misreport. Rijnsdorp et al. [30] note that a management system intended to control exploitation rates but which only records the portion of fish landed cannot be expected to result in sustainable fisheries. They advocate using transferable effort controls rather than ITQs, and discuss ways of making the switch. Turner [11] advocates moving to denominating quotas by landed value rather than landed weight, which would reduce the incentive to misreport the less valuable part of the catch of each species. Copes [37,38] questions whether ITQ management systems are capable of restraining catch, and suggests that limited entry licensing systems with non-transferable licences and effective buy-back provisions may be preferable in some fisheries.

None of these alternatives seem particularly attractive, and in the context of the West Coast hoki fishery major changes are not warranted. The WCSI hoki fishery targets spawning aggregations, and only about 18% of the catch by weight is incidental bycatch. The limit on hoki landings provides some control on the catches of the various bycatch species. There is not a great deal of bycatch to misreport. However, if reporting of bycatch is equally biased in other fisheries with more bycatch, the issue cannot safely be ignored.

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