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DISCARDS AND REVENUES IN MULTISPECIES GROUNDFISH TRAWL FISHERIES MANAGED BY TRIP LIMITS ON THE U.S. WEST COAST AND BY ITQS IN BRITISH COLUMBIA

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ABSTRACT

The problem of multispecies fisheries, in which more productive and less productive species are caught together, is approached differently in the multispecies groundfish trawl fisheries of the U.S. West Coast and British Columbia (B.C.). In 1997 their management systems diverged: the former continued using trip limits, but the latter turned to individual transferable quotas (ITQs) combined with full observer coverage and the deduction of marketable discard mortality from quotas. U.S. requirements to rebuild overfished West Coast species have led to reduced trip limits, restrictions on fishing gear, and large area closures, which have decreased catches of species that are not overfished, increased discards of marketable fish, and decreased per-vessel groundfish income to US$220,000. In B.C., total catches have remained stable while individual incentives to retain marketable catches and to improve economic efficiency resulted in low marketable discard fractions, increased ex-vessel prices, and higher per-vessel revenue (US$420,000–US$500,000). If the B.C. system were implemented in the West Coast fishery, total revenue would probably improve through increased use of species that are not overfished, lower marketable discard fractions, and higher ex-vessel prices. Revenue increases may be hampered by restrictions imposed by the overfished species, but would probably exceed the additional observer costs.

Multispecies fisheries are problematic for fisheries managers because more productive and less productive species are caught together. If each species can be caught selectively, then the overall optimum yield is the sum of the optimum yields for the individual species, but if selectivity is imperfect, the industry can obtain the overall optimum yield only by overfishing some species and underfishing others (e.g., Ricker, 1958; Paulik et al., 1967; Hilborn et al., 2004). If overfishing is not allowed for any species, then the total yield will be much lower. For example, Hilborn et al. (2004) modelled 12 species in the U.S. West Coast groundfish trawl fishery and showed that the fishery would have to forego more than 90% of the potential yield to avoid overfishing any species. The "multispecies problem," framed in this way, appears to present a straightforward trade-off between maximizing economic benefits (by increasing catches) and minimizing ecological harm (by decreasing catches), but the underlying premise of the work cited above is that species in multispecies fisheries are caught in fixed proportions. In reality, fishers are able to alter fishing gear, season, or location to change the proportions of species in their catches and may therefore be able to select those species that are plentiful and avoid species that are in need of rebuilding. The management solution is to create incentives for fishers to avoid some species and select others.

Two common ways of creating these incentives are trip limits and individual transferable quotas (ITQs). Under trip limits each fisher is allowed to retain catches up to the trip limit for each species, but when the trip limit is exceeded, any additional catches of that species must be discarded. By altering the trip limits for the various species, managers can change the incentives for fishers to select each species, but

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when trip limits for some species are small, fishers are more likely to exceed the trip limit with a single large catch and may also choose to continue fishing for co-occurring species while discarding catches of the constraining species. Discard fractions (discards as a fraction of fish caught) therefore generally increase when trip limits are lowered (Pikitch et al., 1988). Trip limits have been employed in multispecies fisheries including those on the U.S. West Coast, in British Columbia (B.C.), and in the U.S. northern Gulf of Mexico reef-fish fishery (Richards, 1994; Babcock and Pikitch, 2000; Weninger and Waters, 2003).

In a system of ITQs—also called individual fishing quotas or dedicated access privileges in the U.S. and individual vessel quotas in Canada—the total allowable catch (TAC) is divided among eligible fishers, and the fishers decide when to fish their shares (Christy, 1973; Moloney and Pearse, 1979). ITQs are transferable, so fishers can buy or lease quota to cover catches in excess of their quota holdings and can sell or lease their quota to other fishers if they want to leave the fishery with compensation. ITQs are argued to provide improved economic efficiency, increased stewardship, increased fishing flexibility, and reduced overcapitalization (e.g., Squires et al., 1995; Grafton, 1996; National Research Council, 1999). Negative effects sometimes attributed to ITQs include social issues relating to the greater control exerted by quota owners than by those that lease quota (e.g., Eythórsson, 2000; Bradshaw, 2004) and the perception that ITQs run counter to public ownership of fisheries resources (e.g., Macinko and Bromley, 2002). ITQs have been implemented in many fisheries, including multispecies trawl fisheries in Nova Scotia, New Zealand, Australia, and Iceland (Sissenwine and Mace, 1992; Pascoe, 1993; Arnason, 1996; Dupont and Grafton, 2001). In multispecies fisheries, despite the greater flexibility offered by ITQs, fishers still find it difficult to match quota holdings to catches, and discarding is often reported as a problem (e.g., Annala et al., 1991; Squires et al., 1998).

In the study reported here, I evaluated the management strategies employed in two multispecies trawl fisheries: the U.S. West Coast groundfish fishery and the British Columbia groundfish fishery. These fisheries are similar in that they both catch more than 70 species, many of which straddle the boundary between the two fisheries. Comparable vessels and gear types are used, and the resulting products are supplied to the same markets, primarily to the U.S. and Japan. The West Coast fishery includes many more overfished species, places greater emphasis on biological sustainability, and therefore imposes far greater restrictions on fishing effort. In contrast, the B.C. fishery has fewer overfished species and places a greater emphasis on economic performance. The West Coast fishery has monitored trends in abundance for a long time, but is less able to estimate current catches and discard rates. The B.C. fishery does not have long survey series, but the 100% observer program reports detailed positional data on catches and discards in addition to comprehensive sampling of ages and lengths.

Both fisheries were once managed under trip limits (Branch et al., 2005), but the U.S. West Coast fishery continued under trip-limit regulations while, in 1997, the B.C. fishery adopted a full ITQ system with 100% observer coverage and the deduction of marketable discards from quotas (Turris, 2000; this issue). The West Coast fishery has historically been larger than the B.C. fishery, both for Pacific whiting (see Table 1 for species names), a large-volume but low-price fish, and for the more valuable nonwhiting sectors (Figs. 1, 2). At present, the West Coast fishery is subject to severe reductions in fishing effort on eight species declared overfished.

Table 1. Family names, scientific names, and common names of fish species referred to in the paper.

Family	Species name	Common name
Anoplopomatidae	*Anoplopoma fimbria* (Pallas, 1814)	Sablefish
Gadidae	*Gadus macrocephalus* Tilesius, 1810	Pacific cod
Hexagrammidae	*Ophiodon elongatus* Girard, 1854	Lingcod
Merlucciidae	*Merluccius productus* (Ayres, 1855)	Pacific hake (whiting)
Pleuronectidae	*Atheresthes stomias* (Jordan & Gilbert, 1880)	Arrowtooth flounder
	Eopsetta jordani (Lockington, 1879)	Petrale sole
	Glyptocephalus zachirus Lockington, 1879	Rex sole
	Hippoglossus stenolepis Schmidt, 1904	Pacific halibut
	Microstomus pacificus (Lockington, 1879)	Dover sole
	Parophrys vetulus Girard, 1854	English sole
Rajidae	*Raja binoculata* Girard, 1855	Big skate
	Raja rhina Jordan & Gilbert, 1880	Longnose skate
Sebastidae	*Sebastes aleutianus* (Jordan & Evermann, 1898)	Rougheye rockfish
	Sebastes alutus (Gilbert, 1890)	Pacific ocean perch
	Sebastes borealis Barsukov, 1970	Shortraker rockfish
	Sebastes crameri (Jordan, 1897)	Darkblotched rockfish
	Sebastes entomelas (Jordan & Gilbert, 1880)	Widow rockfish
	Sebastes flavidus (Ayres, 1862)	Yellowtail rockfish
	Sebastes goodei (Eigenmann & Eigenmann, 1890)	Chilipepper rockfish
	Sebastes levis (Eigenmann & Eigenmann, 1889)	Cowcod
	Sebastes melanops Girard, 1856	Black rockfish
	Sebastes paucispinis Ayres, 1854	Bocaccio rockfish
	Sebastes pinniger (Gill, 1864)	Canary rockfish
	Sebastes ruberrimus (Cramer, 1895)	Yelloweye rockfish
	Sebastes spp.	Rockfish
	Sebastolobus alascanus Bean, 1890	Shortspine thornyhead
	Sebastolobus altivelis Gilbert, 1896	Longspine thornyhead
	Sebastolobus spp.	Thornyheads

The West Coast system of trip limits and other restrictions has resulted in decreased catches of species not considered overfished, increased discarding of marketable species, and decreased groundfish income per vessel, but the introduction of ITQs (together with full observer coverage and the deduction of marketable discard mortality from quotas) to the B.C. fishery has reduced discards, increased ex-vessel prices, and increased income per vessel. Overall revenue would probably be increased in the West Coast fishery if the suite of measures in B.C. were introduced there.

The Two Fisheries

West Coast Fishery.—The West Coast fishery operates off the states of Washington, Oregon, and California, catching a diverse group of species. Since 1982 it has been governed by trip limits on at least some species. Over time, trip limits were gradually reduced and the period to which they applied was extended from a single trip to weekly, monthly, and finally bimonthly cumulative landing limits. For simplicity these cumulative limits will be referred to as "trip limits" throughout. Trip limits are the same for all vessels in the West Coast fishery.

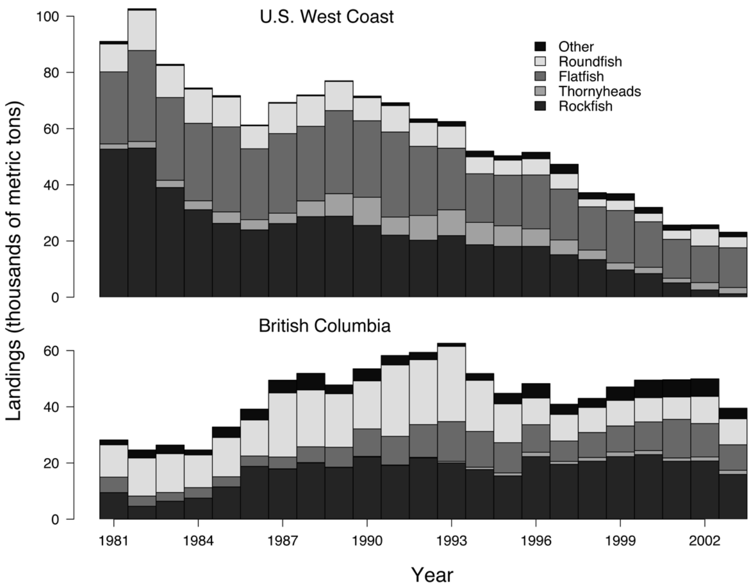

Figure 1. Total landings (thousands of metric tons) of major groups of species in the U.S. West Coast and British Columbia fisheries (1981–2003), excluding Pacific whiting.

Monitoring of this fishery has consisted of regular trawl surveys conducted since 1977 in addition to formal stock assessments on many species. Landings are recorded and combined with estimates of historical discard rates to yield total mortality estimates. As trip limits have changed over time, potentially resulting in changes in discard rates, two biological monitoring programs have been implemented to update the original estimates of discard rates (from those in Pikitch et al., 1988): the Enhanced Data Collection Program (EDCP) from 1995 through 1999 and the West Coast Groundfish Observer Program (WCGOP) from 2001 to the present. These programs were intended to provide biological monitoring and not enforcement, so fisher behavior is unlikely to have been affected by the presence of observers. The EDCP operated mainly off the Oregon coast (where the majority of fishing occurs), but sampling may not have been representative of the fishery as a whole, whereas the WCGOP was designed to achieve random sampling of the entire fishery. Under the WCGOP, a vessel was selected and all that vessels' trips for an entire 2-mo trip-limit period were observed. The WCGOP coverage of the West Coast fishery was 13% of the landed tonnage in 2001–02 and 16% in 2002–03.

In recent years, stock assessments revealed that lingcod and seven rockfish species were overfished. Mandatory rebuilding of these stocks has resulted in a variety of fishery regulations and substantial declines in catches, particularly for rockfishes (Fig. 1). The most prominent of these regulatory changes is major reductions in trip limits for the overfished species. For example, trip limits for canary rockfish declined 20-fold, from 2700 kg per month in 1995 to 45–270 kg per 2 mo in 2000. The reductions applied not only to overfished species, but also to co-occurring species whose stocks were above spawning-biomass target levels, so that fishers would have less incentive to continue fishing after reaching the trip limits for the overfished species.

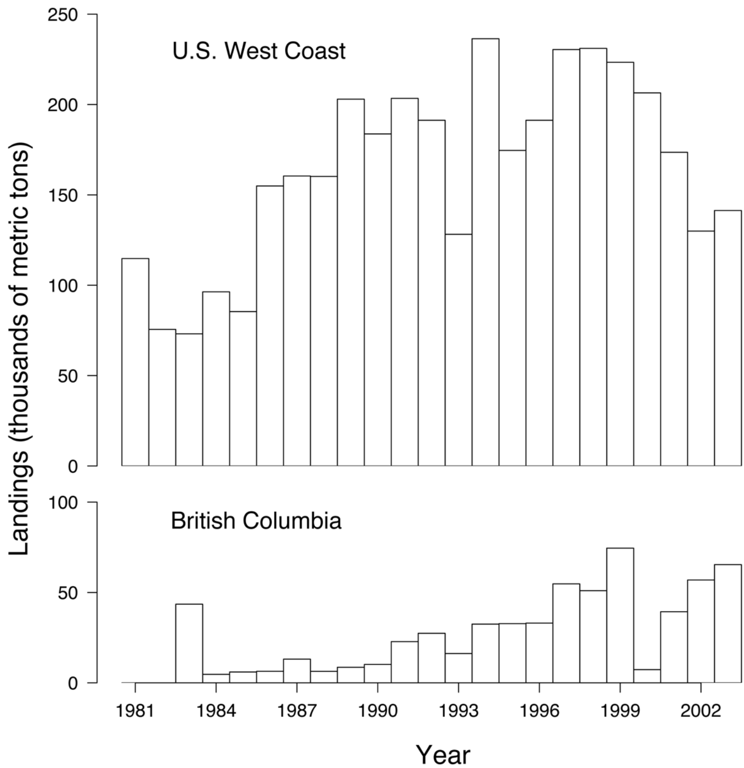

Figure 2. Total landings (thousands of metric tons) of Pacific whiting in the U.S. West Coast and British Columbia fisheries (1981–2003).

Continued fishing would lead to further mortality of the overfished species because their gas bladders expand when they are brought to the surface.

One of the problems of trip limits is the lack of individual responsibility for catches. If one fisher catches large quantities of an overfished species, the consequences are ultimately shared by the whole fleet and not borne by the individual. Additional regulations aimed at protecting the overfished species include gear restrictions and area closures. The use of large footrope trawl gear (which can fish on rocky grounds) was restricted in 2000 to protect rockfish species in their preferred habitat (Hannah, 2003). Several areas have been closed to trawling to protect certain species and species groups, notably the Cowcod Conservation Area (southern California, 2001), Yelloweye Rockfish Conservation Area (northern Washington, 2002), and Rockfish Conservation Areas (coastwide, 2003). These closed areas are collectively known as Groundfish Conservation Areas, and their geographic limits vary with gear, latitude, and season. In effect they have closed most of the shelf region, forcing fishers to concentrate on either shallow-water flatfish species (e.g., petrale sole, rex sole, and English sole) or deep-water species (primarily Dover sole, shortspine thornyhead, longspine thornyhead, and sablefish). Since 2004, vessels have been required to carry satellite locators or vessel monitoring devices for enforcement purposes. Management measures have also included periodic trawl closures when the catch limits for some species will clearly be exceeded. In this fishery an "allowable biological catch" is typically modified by rebuilding and other concerns to produce an "optimum yield," which functions as the catch limit for all gear types fishing groundfish. Overharvesting by any of the groundfish sectors can in theory cause closure of all groundfish sectors, as in 2003 when projected overages by the recreational sector resulted in the closure of the limited-entry trawl fleet (PFMC, 2003).

The West Coast fishery has been greatly overcapitalized for many years. The strategic plan of the Pacific Fishery Management Council (PFMC) indicated that the fleet should be reduced by at least 50% (PFMC, 2000) prior to recent reductions in allowable catches. At that time, 263 limited-entry permits and 225 vessels were active, although a vessel buy-back program in December 2003 reduced the number of permits to 171. Here, I focus on the period before the buy-back because data are not available for assessment of the buy-back's impact.

The strategic plan also called for ITQs to be implemented in the trawl fishery (PFMC, 2000). Previously, a 1991 control date had been set for the trawl fishery to ensure that any allocation of ITQs would be based on pre-1991 catch histories, but PFMC efforts had been focused on the possible implementation of ITQs in the fixed-gear sablefish fishery. In any case, consideration of ITQs in the U.S. was postponed from 1996 to 2002 by mandate of the Magnuson-Stevens Fishery Conservation and Management Act. Since the moratorium expired, the PFMC has started evaluating the use of an ITQ program for the West Coast fishery, but trip limits remain the primary means of limiting catches.

In summary, the West Coast fishery employs a top-down but egalitarian approach to management. All commercial fishers are treated equally and are constrained by identical trip limits, gear regulations, and closed areas, but this approach has been strained by the rebuilding requirements of the eight overfished species.

British Columbia Fishery.—The B.C. fishery catches a suite of species similar to that of the West Coast fishery and used to be governed by trip limits, but continual TAC overruns, discarding problems, and a dissipation of economic benefits led to the closure of the fishery in September 1995 (Turris, 2000, this issue). When it reopened in February 1996, vessels were required to carry observers to supplement the 100% dockside monitoring system that had been introduced in 1994. Observer costs were levied on a fixed per-day basis, and as a result some smaller vessels have sold their quota and left the fishery. The largest vessels also tended to leave the fishery because medium-sized vessels proved more profitable under the new management system. The observers, which are still used in the fishery, record both catch and discards, determining the marketability and the estimated mortality of all discarded fish. Marketability is based on size limits determined in conjunction with processors, whereas assumed mortality rates are based on knowledge about each species. For example, rockfish discards (whether alive or dead) are assumed to suffer 100% mortality, whereas discarded sablefish are assumed to have suffered 10% mortality for the first two trawl hours and 10% per additional hour. The retained catch in addition to the estimated mortality of marketable discarded fish was deducted from trip limits for each species.

In April 1997 this system was replaced by ITQs, which were allocated to vessels on the basis of their length (30%) and catch history (70%). Although quota shares could only be sold and not leased, fishers developed contracts that were leases in all but name. Leasing is now allowed. Under ITQs, full observer coverage remained, as did the deduction of marketable discard mortality from individual vessel quotas.

Both of these elements are central to the operation of the ITQ program. ITQs were imposed for 55 species-area combinations initially, and two more species (big skate and longnose skate) were added in 2002–03. Under ITQs, fishers have increased flexibility because they are able to buy quota for areas (or species) about which they are knowledgeable and sell quota to other fishers who know more about different areas or species. Individual accountability is a key feature of the ITQ program: fishers who catch in excess of their ITQ holdings (beyond a certain amount of under- and overcatch that is allowed and is carried forward to the following year) and are unable to buy or lease quota from other quota holders, will be barred from bottom trawling for the remainder of the year.

ITQs are allocated as a proportion of the TAC for each species. TACs in the B.C. fishery are generally set on a species-specific basis, with the provision that catches be sustainable and that overfished species be rebuilt, typically to >25% of historical biomass levels (R. Stanley, pers. comm.).

The B.C. fishery includes fewer overfished species than the West Coast fishery for two basic reasons. First, the formal overfishing designation does not exist in B.C. Several species have, however, experienced substantial reductions in allowable catches in recent years, including Pacific halibut, of which allowable by-catch declined from 900 mt in 1991 to around 140 mt in 2004; yelloweye rockfish, which declined from 48 mt in 1996 to < 10 mt in 2004, and rougheye rockfish and shortraker rockfish, which declined by about 50% between 1996 and 2004 (DFO, 1994, 1995; FOC, 2003). Second, the B.C. fishery has not conducted surveys over a long time period, nor are in-depth stock assessments conducted on as many species.

The B.C. fishery uses closed areas (termed Rockfish Conservation Areas) as a management tool. These areas are numerous (89 in 2004), but small, and are intended to protect inshore rockfish species from the effects of fishing (FOC, 2003).

In summary, the B.C. fishery now employs a flexible, incentive-based approach that rewards fishers able to catch mainly plentiful species while penalizing fishers who catch species subject to constraining quotas. Such species will have high quota lease prices, potentially higher than their ex-vessel value, encouraging avoidance of areas where they occur and the gear types most likely to catch them. Marketable fish are counted against quota whether they are discarded or retained, so fishers have little reason to discard fish of marketable size. Full observer coverage and the requirement to cease bottom trawling if catches exceed the quota for any species in a given area are important components of the regulatory system.

Methods

Estimated Value of Uncaught West Coast Chilipepper and Yellowtail Rockfish.—West Coast fishers lose income when restrictive trip limits (intended to limit by-catch of overfished species) prevent them from taking the full allowable catches of the target species. This loss of income should be considered a consequence of trip limits if the fishers could have increased their catches under less restrictive limits without increasing their catches of overfished species. Chilipepper and yellowtail rockfish are potentially valuable species that could probably sustain higher catches; their spawning biomasses are thought to be above the target levels for this fishery.

To determine whether restrictive trip limits have reduced annual catches of these species, I converted their historical trip limits from 1985 to 2003 into monthly equivalent trip limits by dividing limits by 0.23 (for trip and weekly limits), 0.46 (2-wk limits), 1 (monthly limits), 2

(2-mo limits), or 3 (3-mo limits) as appropriate. In the earliest years, a "trip" was required to be 1 wk in the southern region, but a week could include multiple trips in the north. I calculated the correlation between the sum of the monthly equivalent trip limits and the corresponding annual landings. The values (V) of uncaught catch limits (TAC_y) for chilipepper and yellowtail rockfish in years y = 2000 to 2003 were estimated by

$$V_y = P_y\left(TAC_y - L_y\right)$$

Where P is the ex-vessel price and L is the landed weight.

Comparison of Total Discard Fractions.—Annual discard fractions (discards as a fraction of fish caught) for each species were obtained from Branch et al. (2005). The original data for the B.C. fishery were provided by Kate Rutherford (Fisheries and Oceans Canada, pers. comm.) and comprised complete observer coverage of that fishery. Data for the West Coast fishery came from the WCGOP program (NWFSC, 2004) and was based on partial monitoring of the fishery. Although discard fractions may vary during the year in the West Coast fishery in response to changes in trip limits, the systematic sampling design of the WCGOP ensured that this variability was averaged out in the annual estimates of discard fractions.

Estimated Value of Marketable Discards.—For the West Coast fishery, marketable discard fractions (marketable discards as a fraction of total marketable catch) were estimated for 2001–02 and 2002–03. Total retained weight and total discard weight were obtained from Branch et al. (2005) and were based on WCGOP data. Regulatory discards were assumed to be marketable, but the data on reasons for discards were not yet available from the WCGOP. Instead I used the reported percentage of regulatory discards in the EDCP program (data were obtained from the PFMC, http://www.pcouncil.org/bb/2004/1104/e6b_at.pdf). Trip limits were higher during the EDCP period than during the WCGOP study. Higher trip limits result in lower discard fractions (e.g., Pikitch et al., 1988; Gillis et al., 1995a) because fewer marketable fish are discarded because of regulations, so the EDCP data should provide a conservative estimate of the marketable discard fractions. Annual ex-vessel prices were obtained from Pacific Coast Fisheries Information Network reports and were the average coast-wide ex-vessel prices for all trawl gear except those for shrimp (obtained from reports prefixed by 058Wtwl and available at http://www.psmfc.org/pacfin/pfmc.html). These data were used to estimate the marketable discard fractions (M_{WC}) and the estimated value of marketable discards (V_{WC}):

$$M_{WC} = \frac{W_{WC} R_{WC}}{L_{WC} + W_{WC} R_{WC}}$$

$$V_{WC} = P_{WC} R_{WC} W_{WC}$$

Where W_{WC} is the total discard weight, R_{WC} is the fraction of discards caused by "regulations," L_{WC} is the landed (retained) weight, and P_{WC} is the ex-vessel price.

For the B.C. fishery, observers on each vessel recorded retained catch, marketable discards, and unmarketable discards for each ITQ-managed species (K. Rutherford, Fisheries and Oceans Canada, pers. comm.), although marketable size limits were not set for non-ITQ species like arrowtooth flounder. Data on B.C. ex-vessel prices (obtained from J. K. Davidson, Fisheries and Oceans Canada, pers. comm.) were sparse from 2001 onward, so the most recent reliable prices (prior to 2000) were used to estimate the value of marketable discards.

Marketable discard fractions (M_{BC}) and estimated value of marketable discards (V_{BC}) were obtained as follows:

$$M_{BC} = \frac{D_{BC}^{M}}{L_{BC} + D_{BC}^{M}}$$

$$V_{BC} = P_{BC} D_{BC}^{M}$$

Where D_{BC}^{M} is the weight of marketable discards, L_{BC} is the landed (retained) weight, and P_{BC} is the ex-vessel price in the B.C. fishery.

Marketable discard fractions and values were only estimated for the eight species for which at least 30 discard records were available in the EDCP study, estimates of total discards were available from the WCGOP, and marketable size limits existed for the B.C. fishery. These species were important bottom-trawl components in both fisheries.

Throughout the present paper, prices in Canadian dollars were converted to U.S. dollars according to the annual average exchange rate. The U.S.-dollar amounts were then adjusted for inflation to a base year of 2000 according to the U.S. Consumer Price Index.

Estimated Value of Ex-vessel Price Changes Attributable to ITQs in the B.C. Fishery.—Ex-vessel price data were available for both fisheries for 12 species from 1982 through 2000. Ex-vessel prices are affected by many factors, particularly the total market supply and changes in marketing practices. Total market supply is dominated by Alaskan fisheries for most species, and the main markets for both fisheries were Japan and the U.S. Consistent price differences between the fisheries from 1982 through 2000 would therefore be expected to reflect transport costs and product quality (which depends on transport duration), whereas any change in the price differences after 1997 could be attributed to the effects of ITQs in the B.C. fishery. Therefore, the total change in revenue due to ITQs can be estimated by comparison of price differences after ITQs (1997–2000) with those in the pre-ITQ years (1995–1996):

$$V_{BC,y} = \sum_{i} L_{BC,y,i} \left[\left(P_{BC,y,i} - P_{WC,y,i} \right) - \left(\frac{P_{BC,95,i} + P_{BC,96,i}}{2} \right) + \left(\frac{P_{WC,95,i} + P_{WC,96,i}}{2} \right) \right]$$

Where $P_{x,y,i}$ is the ex-vessel price in fishery x and year y for species i, $L_{BC,y,i}$ is the landed weight in the B.C. fishery in year y for species i, and $V_{BC,y}$ is the change in ex-vessel revenue in the B.C. fishery in year y attributed to ITQs.

Comparison of Revenue and Active Vessels in the Two Fisheries.—Total annual groundfish revenue (including Pacific whiting) was obtained for the West Coast fishery (Pacific Coast Fisheries Information Network 020Wtwl reports, http://www.psmfc.org/pacfin/pfmc.html) and for the B.C. fishery (GSGislason & Associates, http://www.agf.gov.bc.ca/fisheries/reports/SWOT/FULL_Report.pdf) for 1994–2002. The number of active vessels (any groundfish landings, including Pacific whiting) was obtained for the limited-entry trawl sector of the West Coast (S. Davis, The Research Group, pers. comm.) and B.C. fisheries (K. Rutherford, Fisheries and Oceans Canada, pers. comm.). Mean groundfish revenue per active vessel was calculated. This estimate does not represent total income for these vessels, as they may have participated in other fisheries.

Results

Estimated Value of Uncaught West Coast Chilipepper and Yellowtail Rockfish.—Monthly equivalent trip limits of both chilipepper and yellowtail rock-

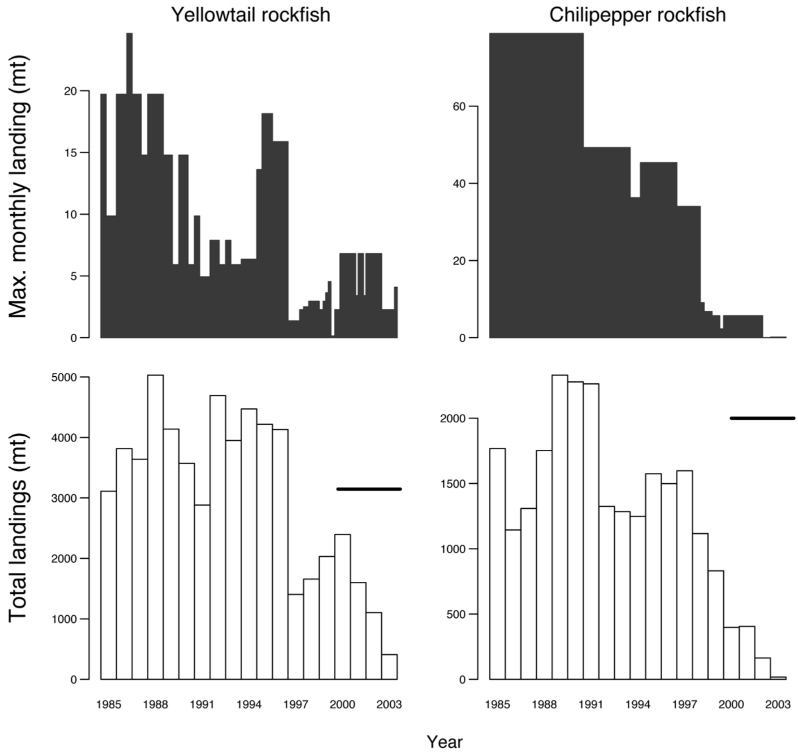

Figure 3. Maximum monthly allowable trip limits in the U.S. West Coast fishery and corresponding annual catches of chilipepper and yellowtail rockfish. Recent catch limits are indicated by horizontal lines in the lower two panels (mt = metric tons).

fish declined sharply over time (Fig. 3). Annual landings of these species were significantly correlated with trip limits: r = 0.80 for chilipepper rockfish, r = 0.67 for yellowtail rockfish (Fig. 3). The total estimated lost revenue from uncaught chilipepper and yellowtail rockfish ranged from US$2.6 million (2000) to US$4.7 million (2003), averaging US$3.7 million per year.

Total Discard Fractions.—Total discard fractions were higher on the West Coast than in B.C. for every species or species group in 2001–02 and for most categories in 2002–03 (Fig. 4). The exceptions in 2002–03 were sablefish (32% on the West Coast and 69% in B.C.), petrale sole (6% and 9%), and other nearshore rockfish (45% and 76%). The overall discard fractions (total weight discarded divided by total catch weight) were 43% in 2001–02 and 31% in 2002–03 for the West Coast fishery and 14% and 19% in the B.C. fishery.

Marketable Discard Fractions and Estimated Value.—For the qualifying species, most of the discards in the West Coast fishery were attributed by captains to trip-limit regulations (Table 2). Estimated marketable discard fractions were higher in the West Coast fishery than in the B.C. fishery for all species in 2001–02 and 2002–03 (Table 3). The mean marketable discard fraction for these species was 20–37 times greater in the West Coast fishery than in the B.C. fishery (28.3%–32.3% and 0.8%–1.6%).

In the West Coast fishery, marketable fish worth an estimated US$5.9 million were discarded in 2001–02 and fish worth US$3.5 million were discarded in 2002–03 (Ta-

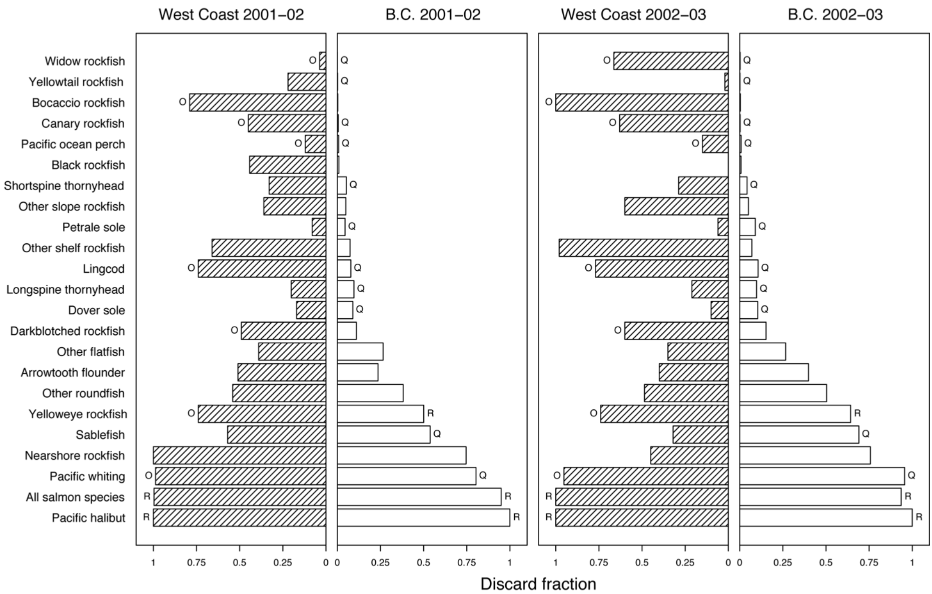

Figure 4. Comparison of the fractions of fish caught during bottom trawling that were discarded in the U.S. West Coast and British Columbia (B.C.) fisheries in 2001–02 and 2002–03 for available species or species categories. The fishing seasons were 1 September–31 August for the West Coast fishery and 1 April–31 March for the B.C. fishery. O, West Coast overfished species with restrictive allowable catches; R, species that must be relinquished; Q, species under ITQ management. Some overfished species were also required to be relinquished. The x-axes are reversed for the West Coast fishery data for easier comparison. Adapted from Branch et al. (2005).

ble 4; mean for the 2 yrs, US$4.7 million). These estimates were dominated by those for discarded sablefish. If sablefish was excluded, the marketable discard value was US$1.3–1.6 million. Discards of Dover sole, lingcod, and shortspine thornyhead were each worth more than US$300,000 annually.

In the B.C. fishery, discarded marketable fish were worth an estimated US$88,000 in 2001–02 and US$168,000 in 2002–03 (Table 4). Dover sole and sablefish were the only species with discards worth more than US$6000 annually.

Estimated Value of Ex-vessel Price Changes Attributable to ITQs in the B.C. Fishery.—Ex-vessel prices were generally higher in the West Coast fishery than in B.C., except for sablefish in most years and for thornyheads and Pacific whiting in some years (Fig. 5). Prices in the B.C. fishery increased relative to West Coast

Table 2. Percentages of discards in the U.S. West Coast fishery that captains designated unmarketable, of poor quality, or discarded due to regulations during 1997–1999 in the Enhanced Data Collection Program study.

Species	Unmarketable	Poor quality	Regulatory
Canary rockfish	0.0	34.8	65.2
Dover sole	36.7	7.8	55.5
Lingcod	2.2	0.3	97.5
Longspine thornyhead	79.5	11.7	8.8
Sablefish	3.6	6.3	90.1
Shortspine thornyhead	23.7	6.8	69.5
Widow rockfish	3.2	0.0	96.8
Yellowtail rockfish	6.2	1.4	92.4

Table 3. Estimated percentages of marketable fish that were discarded in the U.S. West Coast and British Columbia fisheries in 2001–02 and 2002–03. West Coast estimates may be biased because Enhanced Data Collection Program data were used to produce the estimates.

	West Coast		British Columbia	
Species	2001–02	2002–03	2001–02	2002–03
Canary rockfish	35.2	52.4	0.1	0.1
Dover sole	10.0	5.9	2.6	3.8
Lingcod	73.7	76.3	0.1	0.0
Longspine thornyhead	2.1	2.2	0.4	0.6
Sablefish	54.8	30.0	2.6	7.9
Shortspine thornyhead	26.7	24.0	0.3	0.5
Widow rockfish	3.5	65.6	0.0	0.1
Yellowtail rockfish	20.5	2.2	0.0	0.0
Mean	28.3	32.3	0.8	1.6

prices when ITQs were introduced for 10 of the 12 species in 1997, 1998, and 1999 and for eight species in 2000 (Fig. 6). The increased B.C. ex-vessel value (year 2000 US$) attributed to ITQs was US$0.5 million in 1997, US$5.4 million in 1998, US$6.7 million in 1999, and US$0.3 million in 2000, an average of US$3.2 million per year.

Comparison of Revenue and Active Vessels in the Two Fisheries.—The inflation-adjusted groundfish revenue (year 2000 US$) including Pacific whiting in the West Coast fishery declined from a peak of US$84.1 million in 1995 to a low of US$37.2 million in 2002 (Fig. 7). In the B.C. fishery, groundfish trawl revenue declined from US$42.6 million in 1994 to US$33.8 million in 1996 and then averaged US$39.4 million in 1997–2002, an increase of 17% since 1996.

The number of active West Coast limited-entry trawl vessels declined steadily from 250 in 1994 to 169 in 2002 (Fig. 7). In B.C. the number of active vessels increased from 113 in 1994 to 117 in 1996 then declined to 95 in 1997 and further to 81 in 2002 (31% fewer than in 1996).

Groundfish revenue per vessel (year 2000 US$) in the West Coast fishery was highest in 1995–97 (US$350,000–US$430,000) before declining to US$220,000 in 2002. In the B.C. fishery, groundfish revenue per vessel declined from US$380,000 in 1994 to US$290,000 in 1996 before increasing to US$420,000–US$500,000 in 1998–2002. Groundfish revenue per vessel was initially similar but diverged after ITQs were implemented, and by 2002 groundfish revenue per vessel was 2.3 times greater in B.C. than in the West Coast fishery (Fig. 7).

Discussion

Estimated Value of Uncaught West Coast Chilipepper and Yellowtail Rockfish.—The estimated loss in income from chilipepper and yellowtail rockfish catches forgone as a result of restrictions on other species was US$2.6–4.7 million in 2000–03. This estimate is upwardly biased because it is based on the assumption that fishers would be able to reach the catch limit for these two species without exceeding the catch limits for the overfished species. Even if ITQs were implemented and fishers were given increased flexibility in choosing when and where to fish, only a portion of the chilipepper and yellowtail rockfish catch limits would probably be

Table 4. Estimated value (thousands of US$) of discarded marketable fish in the U.S. West Coast and British Columbia fisheries, based on ex-vessel prices (US$/kg) and the mass of marketable discards (mt). Estimates may be biased because Enhanced Data Collection Program data from 1995 to 1999 were used to produce estimates of marketable discards in the West Coast fishery and because British Columbia ex-vessel prices were from 2000 to 2001 and were lower in British Columbia for all species except sablefish.

U.S. West Coast fishery	Ex-vessel prices		Marketable discards		Value	
Species	2001–02	2002–03	2001–02	2002–03	2001–02	2002–03
Canary rockfish	1.04	1.08	30.6	23.0	20.7	16.2
Dover sole	0.80	0.81	999.6	776.9	445.2	347.9
Lingcod	1.88	1.64	286.3	272.1	524.3	434.0
Longspine thornyhead	1.88	1.36	345.8	478.9	57.2	57.5
Sablefish	2.37	2.67	2044.6	905.3	4374.0	2174.1
Shortspine thornyhead	2.36	1.84	275.7	324.9	452.8	414.7
Widow rockfish	1.01	0.99	0.9	7.7	0.9	7.4
Yellowtail rockfish	1.02	1.02	83.3	3.6	78.4	3.4
Total					5,953.6	3,455.1

British Columbia fishery	Ex-vessel prices	Marketable discards		Value	
Species	2000–01	2001–02	2002–03	2001–02	2002–03
Canary rockfish	0.92	0.72	0.61	0.7	0.6
Dover sole	0.67	77.66	118.43	51.7	78.8
Lingcod	1.31	0.98	0.06	1.3	0.1
Longspine thornyhead	1.35	2.37	4.15	3.2	5.6
Sablefish	3.62	8.00	21.38	28.9	77.3
Shortspine thornyhead	1.35	1.46	3.86	2.0	5.2
Widow rockfish	0.80	0.01	0.37	0.0	0.3
Yellowtail rockfish	0.87	0.37	0.28	0.3	0.2
Total				88.1	168.1

caught. Nevertheless, even a small portion (25%) of the available catch limit would be worth more than a million dollars.

Comparison of Total Discard Fractions.—The exceptions to higher discard fractions in the West Coast fishery than in the B.C. fishery were midwater species (Pacific whiting), were minor components in both value and volume in both fisheries (black rockfish, nearshore rockfish, other roundfish), or had discard fractions that were not substantially different (petrale sole). The high B.C. sablefish discard fractions were probably due to an exceptional year class in 2000, which swamped the B.C. fishery (and northern Washington) with undersized sablefish (Branch et al., 2005). Even though overall B.C. discard fractions were substantially lower (14%–19%) than those on the West Coast (31%–43%), discard fractions were all higher than the worldwide mean of 10% for demersal trawl gear (FAO, 2004). Although discard fractions were high for many West Coast species, particularly those designated "overfished," the actual discard volumes for the overfished species were small and included both marketable and unmarketable discards. Although most of the discards in the West Coast fishery were marketable, nearly all of the B.C. discards were unmarketable.

Marketable Discard Fractions and Estimated Value.—Marketable discards for eight species in the West Coast fishery in 2002–03 were more than 20 times greater than those in the B.C. fishery, where fewer than 2% of marketable catches for the corresponding years and species were discarded. The West Coast discards

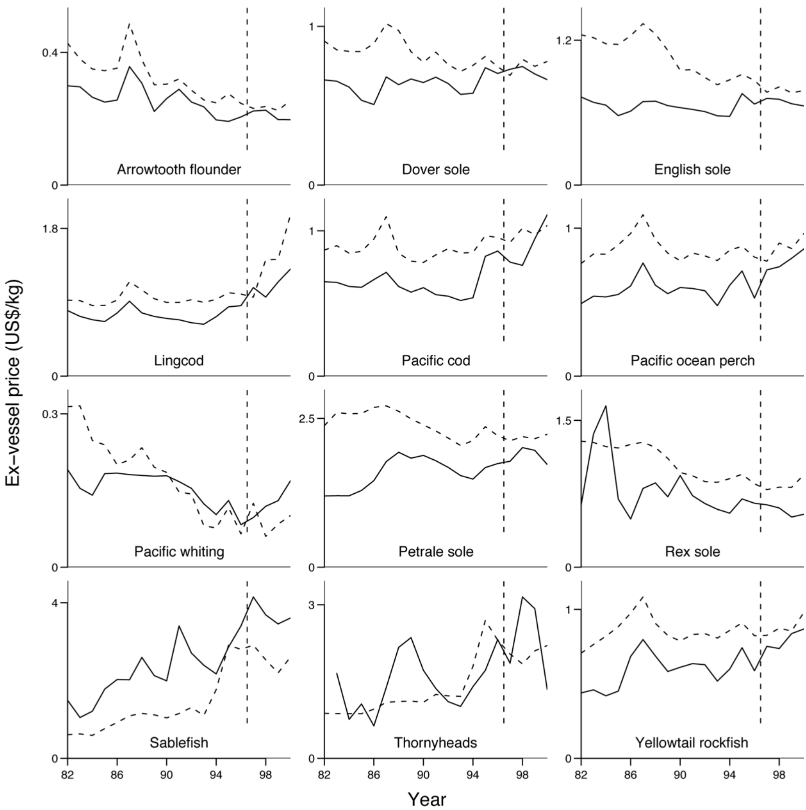

Figure 5. Ex-vessel prices for 12 species in the U.S. West Coast (dashed line) and British Columbia (solid line) fisheries. Prices have been converted to US$ and adjusted for inflation (base year 2000). The vertical dashed line in each panel indicates when ITQs were introduced in the B.C. fishery.

were dominated by sablefish, mainly because captains in the EDCP study reported that more than 90% of sablefish discards were due to regulations, but even if sablefish were excluded, the value of discarded marketable fish was still considerable. The estimates of marketable discards depended on the reasons given by captains for discarding in the 1997–99 EDCP study and should therefore be treated with caution. The proportion of discards due to regulations may have been greater in 2001–03 than during the EDCP study (1995–99) because trip limits were more restrictive in the later years. On the other hand, a general criticism of the reporting method is that captains may not have reported their reasons for discarding truthfully, and their reasons for discarding have not been independently verified. In addition, restrictions on large footrope gear and the implementation of the closed areas may have led to a reduction in the proportion of discards due to regulations. Finally, because the EDCP study focused on the Oregon trawl fleet, some fishing strategies or fleet sectors may not have been observed in proportion to their contribution to the entire fishery. More recent data on the captain-recorded reasons for discarding would have been preferable, but those results, although recorded by the WCGOP (NWFSC, 2003), have not yet been validated and released.

Although these results should be treated with caution, the EDCP results would need to be biased by more than an order of magnitude to reduce the value of the West

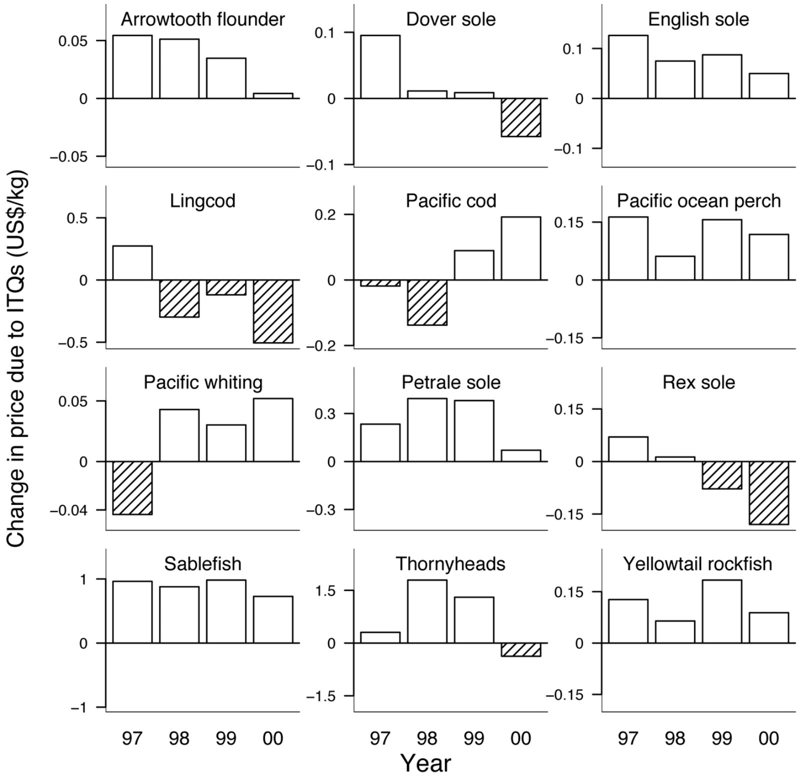

Figure 6. The change in ex-vessel prices that was attributed to ITQs for 12 species in the British Columbia fishery in 1997–2000. White bars indicate an increase in prices, gray bars a decrease in prices. Prices are adjusted for inflation (base year 2000).

Coast discards to the levels in the B.C. fishery. Previous studies have also suggested that West Coast trip-limit regulations result in substantial discards of marketable fish. Branch et al. (2005) estimated that the value of discarded lingcod and shortspine thornyhead was US$0.7–0.8 million, similar to the US$0.8–1.0 million reported here. Pikitch et al. (1988) estimated that lost value of widow rockfish and sablefish discards due to trip limits in 1985–87 averaged US$1.8 million per year. Theoretical models of the West Coast fishery have also suggested that trip-limit management would cause high discard and high-grading rates (Sampson, 1994; Gillis et al., 1995a,b), potentially reducing profits per trip by 66% (Babcock and Pikitch, 2000).

Estimated Value of Ex-vessel Price Changes Attributable to ITQs in the B.C. Fishery.—In many other fisheries, the introduction of ITQs has resulted in increases in ex-vessel prices associated with the more relaxed pace of fishing under ITQs. Changes have included a switch to a more valuable form of the product, better product quality, higher product recovery rates, timing of deliveries to meet market needs, the ability to service specialized markets, and more attention paid to added-value products (Gardner, 1988; Geen and Nayar, 1988; Herrmann, 1996, 2000; Waitt and Hartig, 2000). For example, ex-vessel prices in B.C. for Pacific halibut increased by 55% over those in Alaska when the B.C. longline fishery introduced ITQs in 1991 (Casey et al., 1995).

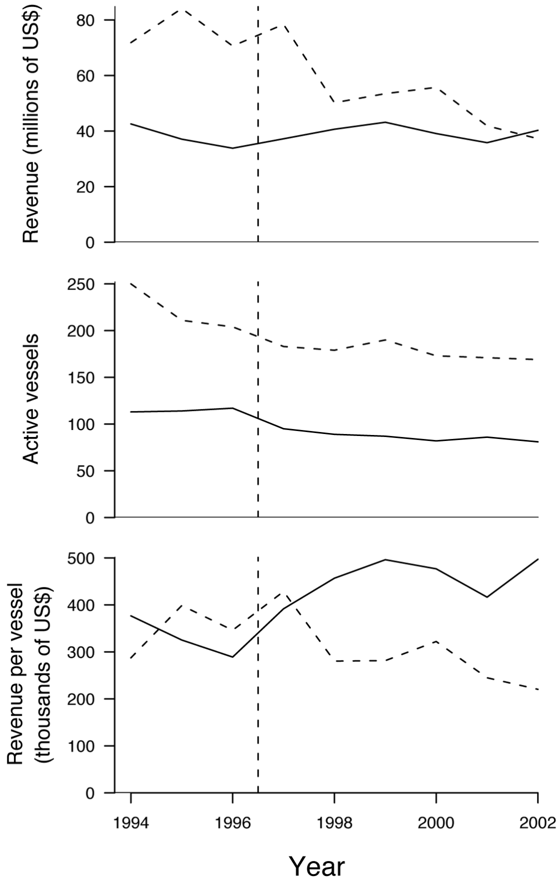

Figure 7. Total groundfish revenue, number of active vessels, and groundfish revenue per vessel in the U.S. West Coast (dashed line) and British Columbia (solid line) fisheries. A vertical dashed line indicates the point at which ITQs were introduced in the B.C. fishery. Revenue (including Pacific whiting) is adjusted for inflation (base year 2000).

When the B.C. fishery moved to ITQs, the increase in ex-vessel prices resulted in an estimated increase in income to fishers of US$12.9 million over the first 4 yrs. The difference in ex-vessel prices between the two fisheries changed in favor of the B.C. fishery for 8–10 of the 12 species in the first 4 yrs. Prices did not increase for all species, probably because of year-to-year market variability in ex-vessel prices. The low price gain in the B.C. fishery in 2000 was due to a low Pacific whiting TAC and catch in 2000 (Fig. 3), when Pacific whiting did not migrate northwards into B.C. waters to the same extent as in previous years.

Matulich and others (Matulich et al., 1996; Matulich and Clark, 2003) argue that, when the derby-style Alaskan halibut fishery changed to ITQs, increases in ex-vessel prices reflected a shift in bargaining power from processors to quota holders (usually fishers) and that this shift resulted in the expropriation of economic rents by the fishers. These authors argued that the shift to an all-year fishery resulted in large amounts of stranded processing equipment and capital and that the increased ex-vessel prices caused processors to leave the industry. An alternative explanation is that the shift from a pulse fishery producing frozen product to a year-round freshproduct fishery decreased processing costs and resulted in higher ex-vessel prices offered to fishers (Hackett et al., 2005). The conditions are different in B.C., where the fishery regulated under trip limits was already year-round, so one would expect little additional stranded capital when the B.C. fishery changed to ITQs. In addition, 10% of the quota (the Groundfish Development Quota) is set aside each year for joint processor-vessel harvest plans, which processors use to leverage the remaining 90% of the quota that is held by vessel owners (Turris, 2000). These circumstances minimize the likelihood that increases in ex-vessel prices are the result of an appropriation of the economic rents by the fishers, although this possibility remains.

Comparison of Revenue and Active Vessels in the Two Fisheries.—Historically, the West Coast fishery has been far larger than the B.C. fishery, but the constraints imposed by rebuilding requirements for the overfished species have resulted in a substantial reduction in non-whiting catches, although whiting catches have remained high. Current groundfish revenue is similar to that in the B.C. fishery, but the B.C. fleet is less than half the size of the West Coast fleet, and B.C. vessels earn 2.3 times more groundfish revenue on average than West Coast vessels.

Changes in fleet size have apparently been driven by different factors in the two fisheries. In the West Coast fishery increased restrictions have resulted in lower profitability, and the number of active permit holders has therefore decreased over time. In the B.C. fishery the fleet size has decreased since ITQs were implemented despite increasing revenues. The decreases in B.C. are partly due to departure of smaller vessels from the fishery because of the additional costs of paying for observers but mainly due to the introduction of ITQs. Under ITQs more efficient vessels can afford to pay more for quota holdings than less efficient vessels. Less efficient vessels can therefore make more money by selling their quota holdings and leaving the fishery, increasing the overall efficiency of the fleet.

Comparison of Biological Performances of The Two Fisheries.—The West Coast management system includes a long time series of trawl surveys dating back almost three decades and intensive stock assessments conducted on 16 of the most important species. This system is therefore likely to detect overfishing as it occurs, at least in the assessed species. As a result, eight species have been declared overfished and in need of rebuilding, and the PFMC has moved to reduce fishing mortality substantially (sometimes by two orders of magnitude or more) of the overfished species. Intensive management has largely constrained total mortality (landings plus discard mortality) to sustainable levels (PFMC, 2004a), but a major problem is that many rockfish species live over 100 yrs (Cailliet et al., 2001) and may take decades to recover to target levels (PFMC, 2004b). The levels of discard mortality and mortality from nontrawl sectors (especially recreational fishing) are also a concern because they are more difficult to limit than commercial landings.

In contrast, because the B.C. fishery does not have long time series of fishery-independent surveys, and in-depth stock assessments are conducted more rarely, overfishing of some B.C. species may not yet have been detected. This possibility has implications for the sustainability of the current TACs. Once TACs have been set, the B.C. system has more control over total fishing mortality. To avoid intersector allocation problems, the TACs are first split among gear types (including an allocation for recreational fishing) before the trawl allocation is assigned to ITQ holders. Discard mortality is estimated directly from records obtained through full observer coverage, which reduces uncertainty associated with estimating discards each year.

Finally, under ITQ management, catches do not exceed the TACs, even though individual fishers are allowed to carry over- and undercatches of up to 37.5%, depending on the species, forward to the following year.

Comparison of Economic Performances of the Two Fisheries.—The emphasis in the West Coast fishery on ensuring biological sustainability has substantially reduced the economic opportunity available to fishers. If the B.C. system were implemented there, the annual income available to West Coast fishers could be increased by millions of dollars, through better ability to catch species that are not overfished, decreases in marketable discards, and higher ex-vessel prices.

The B.C. fishery system, designed to maximize economic revenue, has done so through fleet reductions, near full retention of marketable fish, improved flexibility in choosing when and where to fish, and the efficiency that results from allowing fishers to specialize in particular species or geographic areas. In addition, closer coordination between vessel-owners and processors has resulted in better servicing of markets and increased ex-vessel prices. The ability to trade quota to cover overages is also important. The B.C. fishery is now highly profitable, even though fishing costs have increased because fishers are required to pay for observer coverage. The costs of 100% observer coverage are currently US$1.7–1.8 million per year, which includes administrative costs, overhead, supplies, and training (S. Bunten, Fisheries and Oceans Canada, pers. comm.).

The Role of 100% Observer Coverage.—The 100% observer coverage of the B.C. fishery is crucial to the success of its management plan. It allows for the counting of discard mortality against quotas, providing strong incentives for fishers to avoid species with constraining quotas. This feature would be particularly important for the West Coast fishery because TACs for the overfished species would probably be very low, providing strong incentives to seek species that were not overfished where they were most abundant, even if the result was high by-catch of the overfished species because catch overages could be discarded. In other multispecies trawl fisheries with low observer coverage like those in the Australian South-East Fishery, Nova Scotia, and New Zealand, problems with discarding and high-grading have increased because of the difficulty in matching catches to quotas (Annala et al., 1991; Dupont and Grafton, 2001; Grieve and Richardson, 2001).

The preliminary analyses presented here indicates that the increased revenue from ITQs that would accrue to the West Coast fishery would outweigh the costs of 100% observer coverage, but the low TACs for overfished species may reduce these benefits by constraining catches of other species (e.g., Squires and Kirkley, 1995). Furthermore, a formal cost-benefit analysis of introducing ITQs in the West Coast fishery is currently being conducted by the Trawl Individual Quota analysis team for the Pacific Fisheries Management Council. Final conclusions should await completion of their analysis.

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