NMFS FELLOW - CONTINUING REPORT

NMFS Fellows - 2016-2017
Peter Kuriyama
NMFS/Sea Grant Fellowship - Population and Ecosystem Dynamics - Integrating hook and line survey data and ecological observations to improve stock assessments of key rockfish species in untrawlable habitats
E/I-23
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METRICS & MEASURES

Metric/Measure	Value	Note
Acres of coastal habitat	0	
Fishermen and seafood industry personnel	0	
Communities - economic and environmental development	0	
Stakeholders - sustainable approaches	0	
Informal education programs	0	
Stakeholders who receive information	0	
Volunteer hours	0	
P-12 students reached	0	
P-12 educators	0	

REQUESTED INFORMATION

Publications

Catch shares have not led to catch- quota balancing in two North American multispecies trawl fisheries
Publication Type: Peer-reviewed: Journals (incl. articles), Books, Proceedings, and Other Documents
Publication Year: 2016
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Publisher Info:
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Students Supported

No **Students Supported** information reported

Narratives

2017 Update
Uploaded File: kuriyama_narrative_2017.docx

Partners This Period

No **Partners This Period** information reported

STANDARD QUESTIONS

Community Hazard Resilience

No **Community Hazard Resilience** information reported

Economic Impacts

No **Economic Impacts** information reported

Impacts and Accomplishments

No **Impacts and Accomplishments** information reported

Leveraged Funds

No **Leveraged Funds** information reported

Meetings, Workshops, Presentations

(1)

Type of Event	Sea Grant-sponsored/organized event
Description	NMFS Population Dynamics Fellows Annual Meeting
Event Date	June, 2016
Number of Attendees	30

(2)

Type of Event	Public or professional presentation
Description	SAFS Fisheries Think Tank. Presented on hook-and-line survey simulations

Event Date	October, 2017
Number of Attendees	15

(3)

Type of Event	Public or professional presentation
Description	The effects of catch shares in two U.S. multispecies trawl fisheries. Presented at the World Fisheries Congress in Busan, South Korea
Event Date	May 2016
Number of Attendees	100

Tools, Technologies, Information Services / Sea Grant Products

No **Tools, Technologies, Information Services / Sea Grant Products** information reported

Project details

Peter Kuriyama, ptrkrym@uw.edu

Project number: E/I-23

Project title:

Population and Ecosystem Dynamics - Integrating hook and line survey data and ecological observations to improve stock assessments of key rockfish species in untrawlable habitats

Project update:

My work since March 2016 consists of two projects: (1) simulation study testing factors that lead to bias in hook-and-line survey indices of abundance and (2) comparing the effects of catch shares on spatial patterns of fishing effort in the US West Coast and US Northeast Multispecies fisheries.

Sources of bias in hook-and-line surveys

This was the primary project proposed in the research proposal. Hook-and-line data are collected from areas that are difficult to sample with trawl survey gear. Assessments that incorporate information from untrawlable habitat may provide a fuller representation of population status. Rebuilding for species like yelloweye rockfish and bocaccio can constrain overall fishing activity in multispecies trawl fisheries (see Kuriyama 2016). Many rebuilding species habitats are untrawlable, and the survey may provide improved estimates of abundance. The Northwest Fisheries Science Center has conducted a fixed-site survey in the Couthern California bight for about 15 years.

My simulation evaluates the impact of different aspects of survey design like number of sampling locations, site selection, and number of samples on indices of abundance. Preliminary results indicate that the survey is most robust when populations are below 25% of the unfished level. The relationship between depletion and CPUE becomes more variable as population levels increase. Increasing the number of sampling sites results in a less variable relationship between depletion and CPUE. Preliminary results indicate that the survey captures population declines below a certain threshold. The survey seems less able to detect population increases particularly at levels higher than 50% of unfished biomass.

Effects of catch shares

Catch shares are touted to be a panacea to fisheries management. However, the success of catch shares is likely determined by a number of characteristics of the fisheries. The goal of this work is to present two case studies to identify factors that may lead to positive or negative outcomes.

Comparisons are based on analysis of Vessel Monitoring Data from each fishery. We identified the spatial patterns that emerged in response to catch shares. Preliminary results indicate that the West Coast fishery saw concentration of effort along Oregon and a decrease in effort off northern California and Washington. We are waiting to get appropriate data from the NE fishery.

I published one of my thesis chapters in Marine Policy as well (Kuriyama 2016).

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Catch shares have not led to catch-quota balancing in two North American multispecies trawl fisheries

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ABSTRACT

Catch shares, where annual catch limits are divided among individuals, communities or cooperatives, are a commonly used fisheries management strategy to increase profits and reduce overcapitalization. Usually these quota shares can be sold or leased, which is theorized to allow for greater utilization of fleet-wide quota. However, this catch-quota balancing may not be achieved in multispecies trawl fisheries where it is difficult to selectively target valuable species while avoiding overfished species. Two similar catch-share-managed, multispecies trawl fisheries were compared to evaluate whether catch shares lead to catch-quota balancing. The U.S. West Coast Groundfish fishery has several species with low total allowable catches (TACs) while the Canadian British Columbia Trawl fishery has comparatively higher TACs. Results indicate that the West Coast fishery had a statistically significant decrease in catch-quota ratios from 0.41 in the three years before catch shares to 0.29 in the three years after catch shares. In contrast, the BC fishery experience no statistically significant change in fishery-wide average catch-quota ratios, which were 0.70 in the three years before and 0.62 in the three years after catch shares. In the West Coast fishery, the risk of exceeding quotas for some species may be so high that fishers are unable to achieve high degrees of catch-quota balancing and instead focus on species that can be easily selected with changes in fishing behavior. Multispecies fisheries management has direct tradeoffs between maximizing yield and achieving conservation goals, and these results may highlight the tradeoff between rebuilding overfished species by reducing TACs, and the achievement of catch-quota balancing.

1. Introduction

Multispecies fisheries management confronts a trade-off between overfishing and optimum yield. That is, fisheries that achieve a maximum multispecies sustainable yield will overfish and collapse some stocks [40]; while preventing overfishing across multiple species requires fishers to forego catch and revenue. For example, Hilborn et al. [25] showed that preventing all overfishing would require fishers in the U.S. West Coast groundfish fishery to leave 90% of potential yield in the water [25]. Setting and enforcing low total allowable catches (TACs) for overfished stocks will prevent overfishing but preclude fishers from matching catches to quotas. If overfished stocks have TACs that are orders of magnitude lower than TACs for target species, the risk of exceeding low TACs may constrain fishers' behavior. In these cases, actual catches of overfished stocks can be low relative to the TACs and fishers may have to forego catches of target species.

The constraints of low TACs in multispecies fisheries may be reduced under catch share management. Catch shares are an oft-used management strategy to align environmental and economic incentives to achieve sustainable fisheries [16]. Under catch shares, participating fishers, cooperatives, or communities are granted a share of the TAC. The allocation of rights or privileges to a specified amount of fish ends the race to fish [22], which can grant fishers the flexibility to time catch rates to market prices [22,34]. Catch shares that permit quota transfers provide a market-based method for profitable fishers to buy quota from those operating at a loss. Transferability of quota should reduce fleet size and in turn overcapitalization [5]. Additionally, catch shares with transferable quota offer additional flexibility: fishers can purchase or lease quota to legally land catches over their individual quota holdings, and sell or lease out quota if their catches are under their holdings [15]. The flexibility to transfer quota or cover quota overages

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allows fishers to better match catches with quotas [33].

Taken together, these aspects of catch shares provide both the flexibility and the incentives for fishers to more fully catch TACs. These aspects of catch shares are particularly important in multispecies fisheries where fishers typically have allocations of a wide range of species and some ability to control catch composition by timing trips, fishing in specific locations, or changing gear type [11,12,40]. In practice, however, quotas may not be fully caught in multispecies fisheries for a variety of reasons [16,35]. For example, there may be inefficient transfer markets where little quota is available for lease or sale; it may not be profitable to catch all species; and fishers may not be able to fully avoid species with very low TACs while targeting more abundant species. In New Zealand, to reduce the effect of these issues, fishers can pay fees in lieu of trading or leasing bycatch quota [6,22,27]. The New Zealand system decreases the effect of constraining TACs on target catches but also increases the probability of exceeding TACs for constraining species [5,27]. Allowing exchanges based on market prices between bycatch and target species may grant fishers flexibility when quota markets are imperfect, but the reality is that in most multispecies systems there is no solution to perfectly match catches to TACs [15,33,35].

Although catch shares offer mechanisms to better match catches to TACs, catch shares have mixed overall impacts on ecosystems and fisheries sustainability [10,19,33]. Analyses of stock assessment data for catch share fisheries worldwide found no differences in population biomass and population trajectories after catch share implementation [18,19]. However, the variance of catch and of catch:TAC ratios are greatly reduced after catch share implementation [18,19,29,30]. Reduced variance in catch and in catch:TAC ratios is beneficial for fishing companies when planning business operations. Costello et al. [16] found that landings in catch share fisheries were less likely to collapse, although landings data are not necessarily representative of stock status [32].

1.1. The two fisheries

The U.S. West Coast Groundfish fishery (hereafter West Coast fishery) and British Columbia Trawl fishery (hereafter BC fishery) are two similar fisheries that transitioned to catch share management. The two fisheries are comprised of vessels fishing for similar target species such as sablefish (*Anoplopoma fimbria*), petrale sole (*Eopsetta jordani*), thornyheads (*Sebastolobus* spp.), Dover sole (*Microstomus pacificus*), and a variety of rockfish (*Sebastes* spp.). Both fisheries are limited entry, have similar fleet sizes, mainly use trawl gear, and have comparable fishery-wide TACs [13].

Both fisheries were previously managed under trip limits, in which fishery-wide landing limits for each species and area were set for weekly, monthly, or two-monthly periods. However, trip limits decreased as stock status deteriorated, which led to an increase in discarding as fishers were required to discard species with catches over the trip limits, but could continue fishing for other species, leading to little incentive to fish selectively. Before catch shares in the West Coast and BC fisheries, discarding was not penalized and was not observed reliably. The West Coast fishery had at-sea catch monitoring on only 20% of limited-entry sector trips prior to catch share implementation [8], similar to pre-catch-share coverage rates in the BC fishery [9]. Discarding is wasteful, leads to lost income, and confounds estimates of fishing mortality for stock assessments [4,13]. Thus, trip limits proved ineffective as both fisheries were characterized by overfishing, high discards, and diminished profits. Under catch shares in both fisheries, observer coverage is 100% and discards count towards individual quotas.

One key difference between the fisheries is that the lowest TAC in the West Coast fishery is an order of magnitude lower than the lowest in the BC fishery. For example, in 2011 the lowest TAC in the West Coast fishery was 0.6 mt for yelloweye rockfish (*Sebastes ruberrimus*) compared to 5 mt for the complex consisting of quillback (*Sebastes maliger*), china (*Sebastes nebulosus*), copper (*Sebastes caurinus*), and tiger rockfish (*Sebastes nigrocinctus*) in the BC fishery (Table 1). The next lowest TACs in 2011 were 1.8 mt for cowcod (*Sebastes levis*) and 50 mt for shortspine thornyhead (*Sebastolobus alascanus*) in the West Coast fishery, while the next lowest TACs in the BC fishery were 20 mt for canary rockfish and 61 mt for longnose skate (*Raja binoculata*).

The Pacific Fishery Management Council (Pacific Council) manages the West Coast fishery to prevent overfishing while maintaining an economically sustainable fishery. The low TACs occur because management is required by federal law to rebuild overfished species: bocaccio (*Sebastes paucispinis*), canary rockfish, cowcod, darkblotched rockfish (*Sebastes crameri*), Pacific ocean perch (*Sebastes alutus*), and yelloweye rockfish. Petrale sole (*Eopsetta jordani*) was a rebuilding species, but we consider it a target species, as it has now rebuilt, and is one of the most profitable species in the fishery. In the late 1990s, average biomass levels for rebuilding species were about 30% of the biomass that produces maximum sustainable yield (MSY) (Fig. 1). Many of these species can live longer than 50 years [14], and as a result, it may take many more decades to rebuild the overfished stocks.

The Pacific Council has adopted a number of management policies to rebuild overfished stocks and reduce fishing capacity in the past 20 years. Trip limits were introduced in the early 1980s around the time the Pacific Council officially began managing the groundfish fishery. Trip limits, in which fishers are allowed to catch a fixed amount of fish per trip or time period, are designed to distribute fishing effort throughout the fishing season. Starting in the mid-1990s, the Pacific Council progressively reduced trip limits in order to rebuild stocks. Under trip limits, there were no penalties for discarding, and discard rates for rebuilding species increased as trip limits declined [7]. In 2003, the Pacific Council addressed overcapitalization through a $46 million vessel buyback program to reduce the fleet from 263 to 171 vessels. In addition, as evidence of overfishing of multiple species grew, Groundfish Conservation Areas were declared in the early 2000s, which closed much of the most productive shelf region at depths of 180–450 m to fishing. In combination, these severe constraints on fishing led

Table 1.
Constraining species quota from 2011. Coastwide TACs and area-specific TACs are reported where applicable. Bolded TAC values are considered constraining.

Species	BC TAC	WC TAC
Bocaccio	–	**60**
Canary rockfish	**1004**	**26**
BC Area 3C/3D	**612**	–
BC Area 5A/5B	**268**	–
BC Area 5C/5D	**104**	–
BC Area 5E	**20**	–
Cowcod	–	**1.8**
Darkblotched rockfish	–	**251**
Pacific ocean perch (coastwide)	**6104**	**119**
BC Area 3C	**323**	–
BC Area 3D	**274**	–
BC Area 5A/5B	**2239**	–
BC Area 5C/5D	**2558**	–
BC Area 5E	**710**	–
Longspine Thornyheads	**522**	1966
Quillback, china, copper, tiger	**5**	–
Rougheye rockfish	**823**	–
Yelloweye rockfish	**7**	**0.6**

to greatly reduced profitability despite the rebuilding of widow rockfish (*Sebastes entomelas*), lingcod (*Ophiodon elongatus*), petrale sole, and darkblotched rockfish.

The final major change in West Coast fishery management was the transition from trip limits to catch shares in January 2011, with the explicit goals "to increase net economic benefits, create individual economic stability, provide for full utilization of trawl sector allocation, consider environmental impacts, and achieve individual accountability of catch and bycatch" [31]. From the start, it was recognized that the greatest impediment to full utilization of TACs would be low constraining quotas of overfished species. Yelloweye rockfish offers an extreme example where the TAC for the whole fishery was 0.6 t in 2011, resulting in 65% of the quota owners receiving fewer than 5 kg of quota for the entire year (Fig. 2). For many fishers, the accidental catch of a single yelloweye

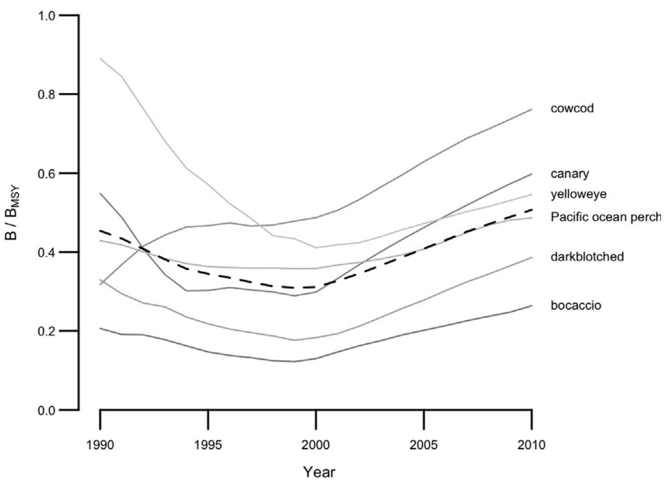

Fig. 1. Trajectories of B/B_{MSY} for constraining species in the West Coast fishery. The black dotted line indicates the average ratio across the six species. Values come from stock assessments for cowcod [17], canary rockfish (Wallace and Cope, 2011), yelloweye rockfish [37], Pacific ocean perch (Hamel and Ono, 2011), darkblotched rockfish [23], and bocaccio [21].

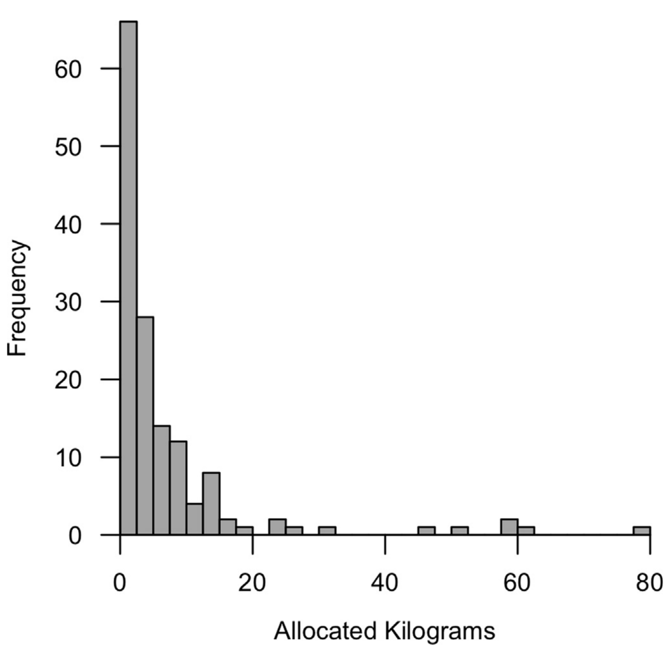

Fig. 2. Histogram of individual quota allocations for yelloweye rockfish (*Sebastes ruberrimus*) in the 2011 West Coast fishery. Forty-six percent of quota owners (n=145) received fewer than 2.3 kg of quota.

rockfish would require a fisher to cease fishing until additional quota could be leased. More catastrophic scenarios included the possibility that a single tow could exceed the entire coastwide yelloweye rockfish TAC, and thereby close the entire groundfish fishery.

In the BC fishery, similar to the West Coast fishery, catch shares were also introduced at a crisis point in the fishery. The turning point was September 1995 when Fisheries and Oceans Canada closed the BC fishery for five months due to significant TAC overages [38]. The fishing industry spent 14 months working with Fisheries and Oceans Canada to agree on the details of a new catch share program. During these discussions, in 1996, the fishery reopened with 100% at-sea observer coverage and 100% dockside monitoring of landed catches, but still governed by trip limits. The costs of the new programs were passed on to the fishing industry, including the $4.4 million cost of observer programs and increased vessel licensing fees (from $14 to $10,342); these fees further reduced the already small profits in the fishery. Subsequently, the fishery moved to catch shares in the form of individual transferable vessel quotas in April 1997. The main driver of catch share implementation was to maintain the economic viability of the fishery. In the BC fishery, vessel owners are allowed to transfer and trade quota to other participating vessels. Fisheries and Oceans Canada has also enforced a number of small closed areas, and fleet size has declined under catch shares although there was no vessel buyback program. Since catch-share implementation, the TACs have remained fairly constant for most species, in contrast to the sharp declines for some species in the 2000s in the West Coast fishery.

The Central California Risk Pool is one unique aspect of the West Coast fishery that began in 2011, at the same time as catch shares. Risk pools are arrangements in which fishers pool quota and make it available for other participants [28]. The Nature Conservancy worked with fishers from Morro Bay, Fort Bragg, and Half Moon Bay to establish the Central California Risk Pool. Risk pool participants leased quota owned by The Nature Conservancy and collaboratively developed spatial fishing plans to avoid bycatch species habitats. Data from the risk pool were compiled from Fort-Bragg-Central Coast Risk Pool Annual Summary Reports. Risk pools and information sharing may improve the abilities of fishers to target valuable species and avoid bycatch species.

1.2. Responses to catch shares

The ability of catch shares to achieve catch-quota balancing were evaluated in these two similar North American fisheries (The West Coast fishery and the BC fishery). Data from before and after catch share implementation in both fisheries were used to examine whether catch shares increased catch-quota balancing, as evidenced by catch:TAC ratios being closer to one. Several possible catch:TAC outcomes could occur assuming that both target and constraining species are unavoidably caught together. Constraining species are considered to be stocks for which the risk of exceeding the TACs is high. The analysis is framed around three hypotheses:

Hypothesis 1.

Fishers will be able to more fully catch the TACs for target species under catch shares. This would arise if fishers can adjust fishing behavior to selectively target specific species and if quota transfers fluidly between fishers to balance overages and underages. Under this hypothesis, the average catch: TAC ratios for target species and the proportion of target species with high catch: TAC values should increase.

Hypothesis 2.

Fishers will be unable to fully catch target species due to the high risk of exceeding low TACs of constraining species under catch shares. Under trip limits, fishers had the ability to discard excess landings so the risk of exceeding trip limits for constraining species was less of a factor. Whereas under catch shares, observers count both landings and discards against quota, so the risk of exceeding TACs for constraining species becomes a limitation on fishing activity. If the risk of exceeding TACs for constraining species is sufficiently high, catch:TAC ratios for target stocks should decrease, and catch:TAC ratios for constraining stocks should be unchanged or decrease under this hypothesis.

Hypothesis 3.

Fishers will be unable to fully catch target species because of limited quota availability for constraining species. If the risk of exceeding TACs for constraining species is manageable, catch:TAC ratios for constraining species should be at or near one, and target species ratios will be unchanged or decrease. Note that throughout the text, constraining stocks are defined to be stocks for which the risk of exceeding quotas is high. However for this hypothesis, the definition of constraining stocks is relaxed as the risk of exceeding constraining stocks is manageable.

2. Methods

2.1. Catch:TAC ratios

Catch:TAC ratios were calculated to measure the abilities of fishers to meet management targets before and after catch shares. Landings and discard data were compiled for the West Coast fishery and summed to calculate total catches. For 2004–2010, landings and discard data specific to the trawl sector were obtained from the West Coast Groundfish Observer Program. Onboard observers estimated discards for monitored vessels. Observer coverage was around 20% of vessels from 2002 to 2010 [8] and 100% of vessels after catch share implementation in 2011. Total catch values, summed across all commercial and recreational sectors for each stock, were obtained from annual discard and total catch reports from 2004 to 2010 (http://www.nwfsc.noaa.gov/research/divisions/fram/observation/data_products/species_management.cfm) and used to calculate TACs specific to the trawl sector. For 2011–2013, total catch values (the sum of landings and discards) for the trawl sector were obtained from the Pacific Coast Groundfish Individual Fishing Quota database (https://www.webapps.nwfsc.noaa.gov/ifq/).

Total allowable catch values were compiled for the West Coast fishery, however the definition of the "TAC" differed through time. From 2004 to 2010, the trawl sector was managed with trip limits instead of quotas. Trip limits were set on a bimonthly basis but were not a hard cap on landings. As a result, TACs for 2004–2010 had to be calculated from coast-wide management values (including all commercial and recreational sectors) reported in annual discard and total catch reports. These coast-wide management values were taken to be those reported as optimum yields or those reported as allowable biological catches if optimum yield values were not listed. For 2011–2013, TACs were the allowable catch limits specific to the trawl sector reported in the Pacific Coast Groundfish Individual Fishing Quota database (https://www.webapps.nwfsc.noaa.gov/ifq/).

Total allowable catch values specific to the trawl sector from 2004 to 2010 were calculated based on the proportion of trawl catches in coastwide catches. Management limits (such as allowable biological catch or annual catch limits) were set by managers for both commercial and recreational sector. However, a trawl-sector-specific TAC value is necessary to keep catch:TAC ratios comparable before and after catch share implementation. The trawl-sector-specific TAC was calculated based on the proportions of trawl catches in total catches:

$$P_{x,t} = \frac{T_{x,t}}{F_{x,t}} \tag{1}$$

where $P_{x,t}$ is the proportion, $T_{x,t}$ is trawl catches, $F_{x,t}$ is total catches for species x in year t. Trawl TAC was calculated as:

$$TAC_{x,t} = PAvg_x * MV_{x,t} \tag{2}$$

where $PAvg_x$ is the arithmetic mean of proportions $P_{x,t}$ from 2004 to 2010 for species x, $MV_{x,t}$ is the coast-wide management value from Annual Groundfish Fishing Mortality reports for species x in year t. If catch:TAC ratios were calculated using $P_{x,t}$ rather than $PAvg_x$, both the numerator and denominator of catch:TAC calculations contain $T_{x,t}$ which subsequently cancels out, resulting in an incorrect measure [See Supplementary materials]. The Pacific Council set both trawl-specific and coastwide management values in 2011–2013, and calculations from this method are highly correlated with the actual trawl-specific TACs (R^2=0.99, Fig. S1). Catches were calculated to be the sum of landings and discards from the trawl sector, because although discards did not count towards bimonthly trip limits from 2004 to 2010, regulations were based on total catches. Discards of lingcod and sablefish were assumed to have a 50% mortality rate, and catch calculations for these species were adjusted accordingly.

For the BC fishery, landings and catch data were obtained from observer data in Fisheries and Oceans Canada's PacHarvest database for 1994–1996 and from publicly available groundfish trawl summary documents for 1997–2013 released by Fisheries and Oceans Canada. TACs were obtained from the Groundfish Integrated Fisheries Management Plans reported annually by Fisheries and Oceans Canada for 1994–1996 and groundfish trawl summary documents for 1997–2013 (e.g. 2012–2013 Groundfish Trawl Summary of Catch vs Available Weight). Fishing seasons in BC are not based on calendar years and for most years start and end in February. For simplicity, we refer to fishing seasons by the predominant year e.g., the fishing season that starts 21 February 2011 and ends 20 February 2012 is labeled 2011.

Average catch:TAC ratios were calculated in the three years before and three years after catch share implementation (West Coast: 2008–2010 vs. 2011–2013; BC: 1994–1996 vs. 1997–1999) at the fishery-wide, group-wide (target, constraining, other), and individual stock scale. Data for the BC fishery were unavailable prior to 1994, thus only the three years before and after could be analyzed. Fishery-wide catch:TAC averages used ratios from all stocks and group-wide averages used ratios from all stocks in each category. All averages were calculated with an arithmetic mean.

2.2. Target and constraining species

Fisheries scientists familiar with each of the fisheries were consulted to identify which species were targeted in each fishery. Based on these discussions, target species were assumed to be Dover sole, sablefish, and lingcod. Additionally, the West Coast fishery targets longspine thornyhead (*Sebastes altivelis*), petrale sole, and shortspine thornyhead, and the BC fishery targets yellowtail rockfish (*Sebastes flavidus*), Pacific ocean perch, yellowmouth rockfish (*Sebastes reedi*), petrale sole, widow rockfish, Pacific cod (*Gadus macrocephalus*), walleye pollock (*Theragra chalcogramma*), and silvergray rockfish (*Sebastes brevispinis*).

Constraining species were assumed to be those with rebuilding plans (West Coast fishery) or those listed as Endangered or Threatened by the Species At Risk Act (BC fishery) in Canada. For the West Coast fishery these species were canary rockfish, Pacific ocean perch, yelloweye rockfish, darkblotched rockfish, bocaccio, cowcod, and widow rockfish. For the BC fishery constraining species were canary rockfish, longspine thornyhead, rougheye rockfish (*Sebastes aleutianus*), yelloweye rockfish, and quillback rockfish. An additional constraining species in BC is bocaccio, which is listed by the Species At Risk Act but must be discarded as part of the BC catch share system.

Data for Pacific whiting (*Merluccius productus*) were excluded from analyses as the fishery is subject to different constraints. Whiting fishers typically use midwater trawls rather than bottom trawls and rarely encounter the most constraining species: yelloweye rockfish [36].

2.3. Hypothesis testing

Permutation tests were used to statistically evaluate the effects of catch shares at the fishery-wide scale and at the categorical scale (target, constraining, and other). Catch:TAC ratios for each stock were sampled without replacement from the six year time period under evaluation. Arithmetic means were calculated across the first three samples ("before") and last three samples ("after") across all stocks of interest. This process was repeated for 1000 iterations. P-values were assigned based on the proportion of iterations with before/after differences more extreme than the observed difference. The BC fishery had insufficient stock-specific data before catch share implementation to conduct this permutation test.

3. Results

3.1. Hypothesis testing

Permutation tests on catch:TAC ratios in the West Coast fishery showed statistically significant declines for the whole fishery, constraining stocks, and other stocks. After catch share implementation, catch-quota balancing for the whole fishery had an observed change of -0.11 ($p=0.001$), constraining stocks had an observed change of -0.25 ($p=0.001$), and other stocks had an observed change of -0.05 ($p=0.02$). Target stocks had an observed change of -0.11 ($p=0.07$). The observed decreases at all levels were most consistent with Hypothesis 2, suggesting that the risk of exceeding constraining species quotas is high.

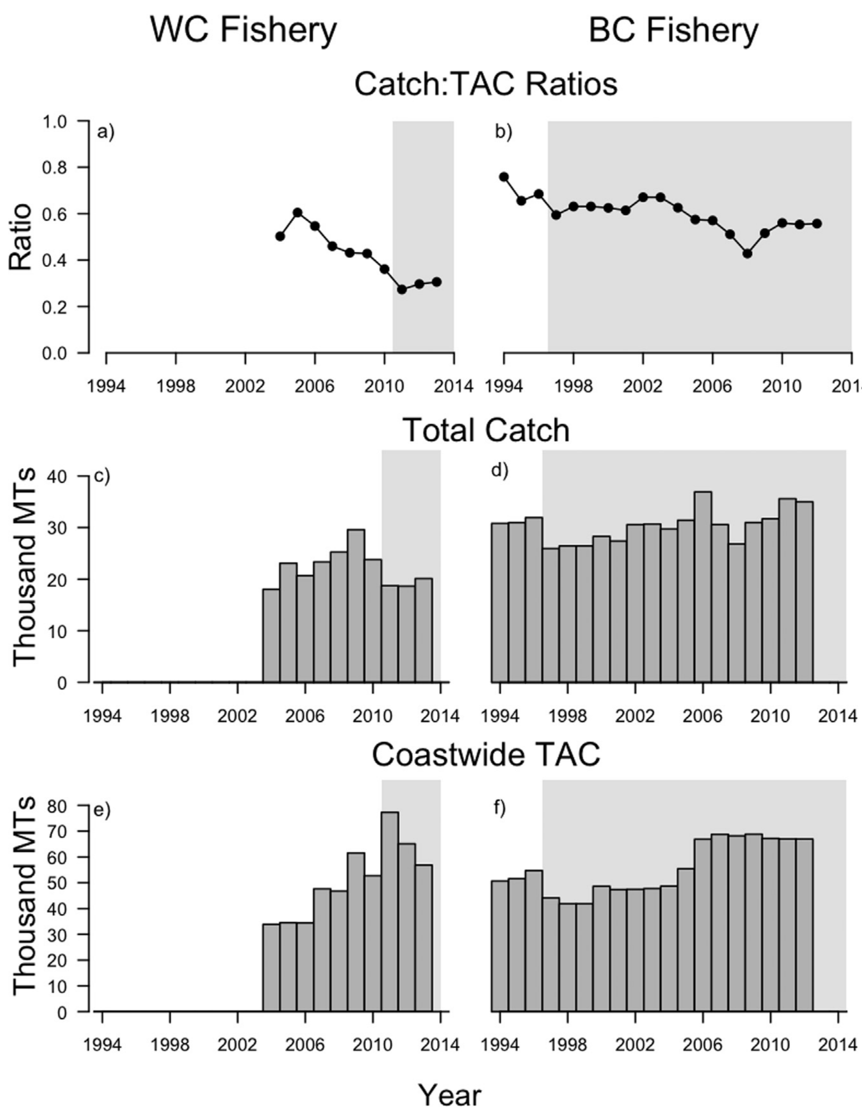

Fig. 3. Fishery-wide catch:TAC ratios (a and b), total catch values (c and d), and TAC values for each fishery (e and f). Pacific whiting excluded from all figures. Years under catch share management (1997–2013 in BC and 2011–2013 in West Coast) are indicated by a light gray background color.

Table 2.
Descriptive statistics from BC and West Coast fisheries.

Fishery wide	3 years before	3 years after
WC average catch:TAC	0.41	0.29
BC average catch:TAC	0.7	0.62
WC summed catches (mt)	78,584	57,492
BC summed catches (mt)	93,662	78,746
WC summed TAC (mt)	161,178	199,225
BC summed TAC (mt)	157,020	127,795
Group averages		
WC targets average catch:TAC	0.62	0.49
BC targets average catch:TAC	0.65	0.67
WC constraining average catch:TAC	0.47	0.22
BC constraining average catch:TAC	NA	0.78

Statistical analyses were not possible in the BC fishery as both target and constraining stocks were managed as mostly complexes prior to catch shares and single stocks after catch shares. Thus, the null hypothesis that catch shares had no effect on catch-quota balancing cannot be rejected. However, the descriptive results below highlight the longer term trends seen in each fishery at different scales.

3.2. Descriptive results

Average catch:TAC ratios at the fishery-wide level showed a decreasing trend in the West Coast fishery (Fig. 3a) and remained generally constant in the BC fishery (Fig. 3b). In the West Coast fishery, catches were low and TACs were high in the three years after catch shares (Fig. 3c and e). In the BC fishery, both catches and TACs were relatively low and catch:TAC ratios were greater than 0.5 (Fig. 3d and f). The averaged catch:TAC ratios, summed catches, and summed TACs are shown in Table 2.

Time series of average catch:TAC ratios at the category level show similar trends to the fishery-wide trends. In the West Coast fishery, target and constraining species have been generally declining since the beginning of the time series (Fig. 4a and c). Maximum catch:TAC ratios for target and constraining species occurred in 2005 (Fig. 4a and c). In the BC fishery, target and constraining species trends have been comparatively stationary (Fig. 4b and d).

In the West Coast fishery, the proportion of target stocks greater than 0.5 was 0.71 (n=21) in the three years before catch shares and 0.40 (n=25) in the three years after (Fig. 5a-b). Sablefish, petrale sole, longspine thornyhead, and shortspine thornyhead had catch:TAC ratios that were over 0.5 in at least one year after catch shares (Fig. 6). The proportion of constraining stocks with catch:TAC ratios greater than 0.5 was 0.39 (n=18) in the three years before catch shares and 0 (n=18) in the three years after (Fig. 5b-c). Darkblotched rockfish, Pacific ocean perch, and canary rockfish had catch:TAC ratios greater than 0.5 in at least one year of the three years prior to catch share implementation (Fig. 6).

In the BC fishery, the proportion of target stocks with catch:TAC

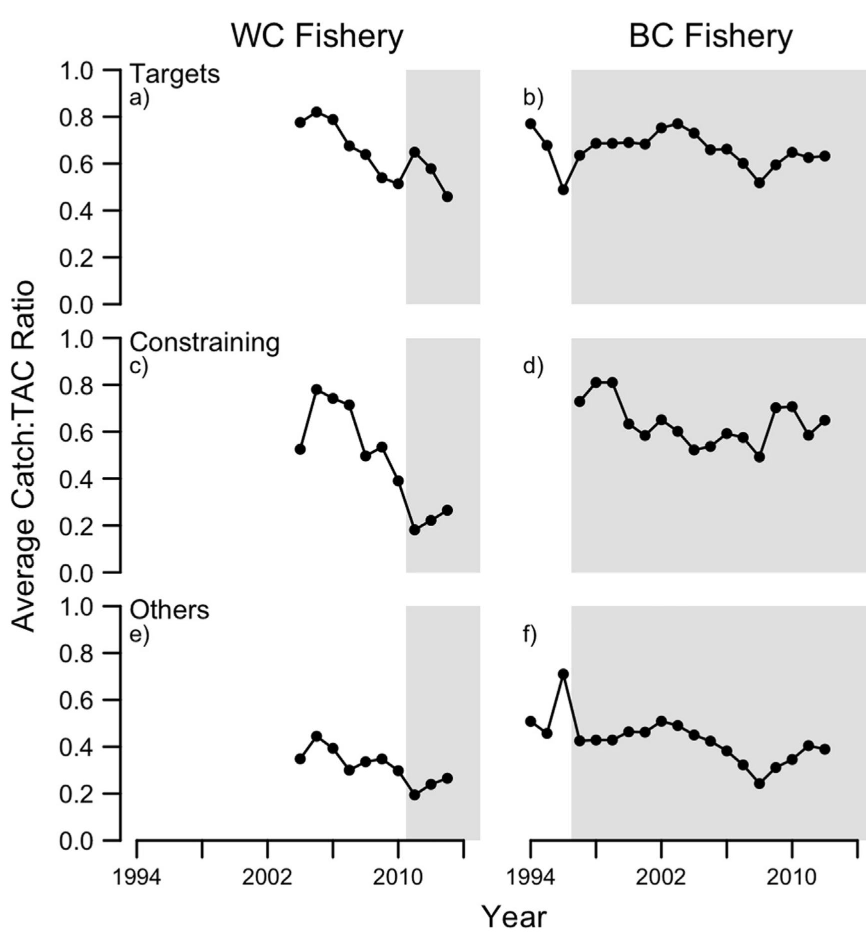

Fig. 4. Plots of average catch: TAC ratio by year from 1996 to 2013 for (a) target species, (b) constraining species, (c) and other species. White bars indicate values from the BC fishery, and gray bars indicate values from the West Coast fishery. Years under catch share management (1997–2013 in BC and 2011–2013 in West Coast) are indicated by a light gray background color.

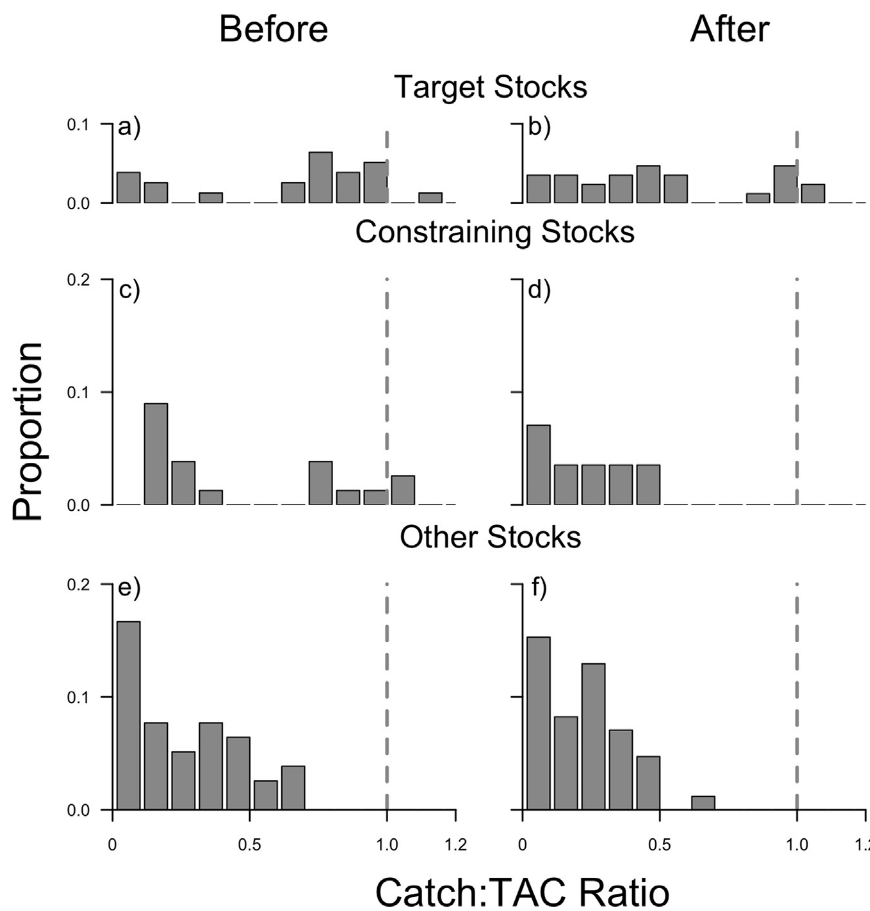

Fig. 5. Histograms for catch:TAC ratios in the West Coast fishery in the three years before (2008–2010; a, c, e) and after (2011–2013; b, d, e) catch share implementation.

ratios greater than 0.5 was 0.58 (n=28) in the three years before catch shares and 0.75 (n=84) in the three years after catch shares (Fig. 7a-b). All target stocks had catch:TAC ratios greater than 0.5 at least once in the years after catch shares (Fig. 8). The proportion of constraining stocks with catch:TAC ratios greater than 0.5 was 100% (n=16) in the three years after catch shares. Constraining stocks prior to catch shares were managed as complexes and excluded from these calculations. Canary rockfish and rougheye rockfish had generally high catch:TAC ratios in the years after catch shares (Fig. 8).

Catch:TAC ratios in the risk pool in the West Coast fishery were similar to the values from the rest of the fishery. Petrale sole in 2012 was the only target species that had a lower catch:TAC ratio in the risk pool than in the fishery (Fig. 6). Darkblotched rockfish and Pacific ocean perch in 2011 and 2012 were the only constraining species that had lower catch-quota balancing in the risk pool than in the fishery (Fig. 6).

4. Discussion

Catch shares did not improve catch-quota balancing in the West Coast and BC fisheries. The West Coast fishery had a statistically significant decline in fishery-widecatch-quota balancing and a decline in constraining and other stock catch-quota balancing. Further, there was little evidence to support Hypothesis 1, that catch shares allow fishers to more fully catch TACs for target species, and little evidence to support Hypothesis 3 that the risk of catching constraining species is manageable. Results suggest that the risk of catching constraining species is high under catch shares, evidenced by the decline in catch:TAC ratios for constraining and target species. Limited data prior to catch shares in the BC fishery precluded statistical analyses, thus the null hypothesis that catch shares have no effect on catch-quota balancing is not rejected. However, the numbers from the BC fishery show that catch-quota balancing under catch shares was comparatively higher than that of the West Coast fishery at the fishery-wide scale and for target and constraining stocks. It seems unlikely that the risk of catching constraining species has an effect on catch-quota balancing in the BC fishery.

The BC fishery had a higher degree of catch-quota balancing than the West Coast fishery – perhaps evidence that quota transfers in BC are quicker and more efficient than those in the West Coast fishery. Both Hypothesis 1 and Hypothesis 3 require quota to flow fluidly among fishers. The high catch-quota balancing, evidenced by catch:TAC ratios >0.75, for both target and constraining stocks in the BC fishery indicates that fishers have developed methods of distributing quota to those in need. This result is consistent with a previous study that identified the movement of quota through barters rather than monetary transactions in the BC fishery [26]. Barter markets in the BC fishery seems to transfer quota to those in need, although it seems less likely for an economically efficient market to develop in the West Coast fishery due to fishers' reluctance to give up constraining species quota. One reason for this is that the risk of exceeding quotas for constraining species is so high that fishers are likely to retain quota until the end of the season (J. Sullivan, pers. communication).

Catch-quota balancing in the West Coast fishery appeared to be more affected by constraining stocks than in the BC fishery. In the West Coast fishery, the risk of exceeding constraining species

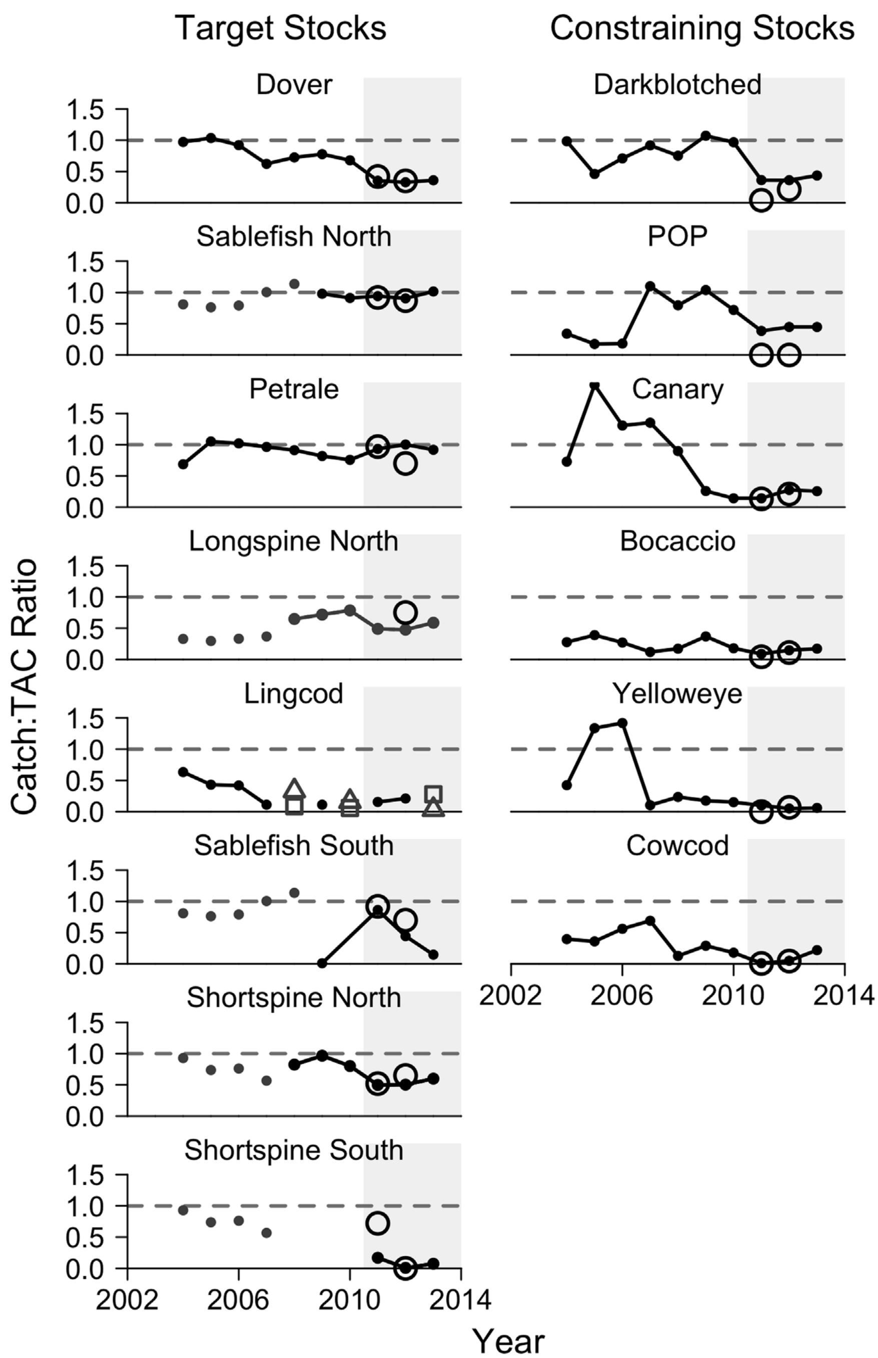

Fig. 6. Time series of catch:TAC ratios for both target and constraining species in the West Coast fishery. Gray shading indicates years under catch share management. In 2008, 2010, and 2013, lingcod were managed as northern (open squares) and southern (open triangles) stocks. Unconnected points in the sablefish, longspine thornyhead, and shortspine thornyhead points indicate years in which the stock was managed on a coastwide basis. There were no TACs for southern shortspine thornyhead from 2007 to 2010. Open circles indicate catch:TAC ratios from the risk pool.

quotas is so high that many fishers are fishing more conservatively or less overall (M. Burden, personal communication). This reduction in effort is seen here, as no constraining stocks had catch:TAC ratios greater than 0.5 in the West Coast fishery. Trawl vessels in multispecies fisheries have demonstrated the ability to adjust fishing behavior to achieve different catch compositions in BC [11] and Alaska [3]. In the West Coast fishery, the high risk of exceeding constraining species TACs may preclude a similar degree of control. The few stocks with catch:TAC ratios near 1 could be selected by timing fishing or switching gear types. Petrale sole form spawning aggregations in winters [24], and sablefish quotas can be transferred to the fixed gear pot sector which is more selective than trawls. Fishers in the BC fishery may also have higher degrees of regional specialization that would lead to high catch-quota balancing for both target and constraining stocks.

Policies such as carryover rules, deemed value systems, and species transformations are designed to grant fishers more flexibility, but it seems unlikely that such policies would improve catch-quota balancing in the West Coast fishery. In these fisheries, carryover rules already grant fishers the ability to transfer unused quota to the following year. Carryovers of up to 10% a single-species TAC are permitted in the West Coast fishery, and in the BC

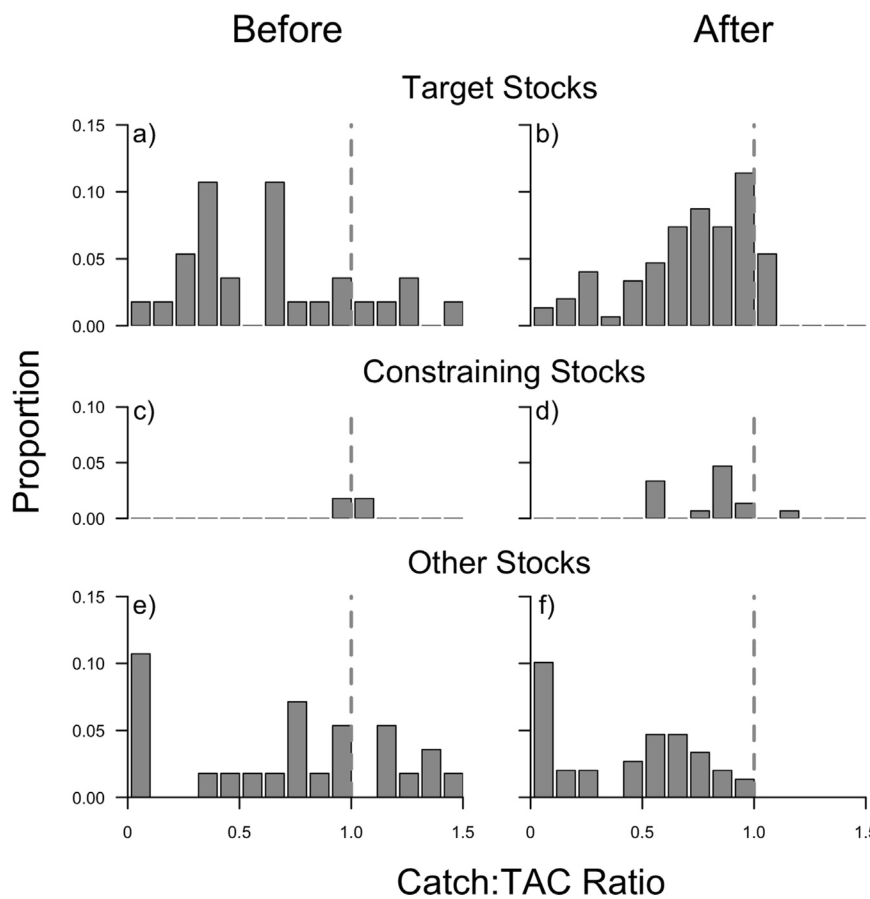

Fig. 7. Histograms of catch:TAC ratios in the BC fishery. Shown are ratios for the three years before (1994–1996; a, c, e) and three years after (1997–1999; b, d, f) catch share implementation. Management complexes in which multiple species were managed with TACs were excluded from this figure. The exception is the constraining stocks panel for before years (c) in which complexes that contained constraining species were included, since no constraining species were managed as a single species.

fishery, carryovers of 30% for most species, 15% for lingcod, and 10% for dogfish are permitted. However, carryover rules were found to have little effect on catch-quota balancing in a meta-analysis of catch share fisheries [30]. Current carryovers of up to 10% have resulted in relatively low catch-quota balancing, and allowances may need to be much greater than 10% to have an effect on catch-quota balancing. Deemed value systems, in which fishers pay fees for landings in excess of quotas, are used in New Zealand to incentivize retention of bycatch and discourage fishers from targeting species without sufficient quota. Bioeconomic simulations of deemed value systems show that overexploitation of bycatch species is avoided when target and bycatch species have low spatial overlap [27]. Allowable catches were exceeded in cases where species had more spatial overlap [27]. These results are not applicable to the West Coast fishery as there is generally a great deal of overlap between target and constraining species, and TACs cannot be exceeded. Catch share fisheries in Iceland allow species transformations in which quota of one species can be converted to quota of another to improve catch-quota balancing. However, this system is similarly inapplicable to the West Coast fishery as the Icelandic system leads to frequent quota overages [39].

Risk pools may be the most feasible means of improving catch-quota balancing in the West Coast fishery. Risk pool fishers achieved higher catch:TAC ratios for some target species with lower catch:TAC ratios for some constraining species (Fig. 6), although no statistical analyses were conducted on risk pool data. Ideally, a risk pool should be large enough to allow fishers to fish with confidence while being small enough to enforce group social norms. A small risk pool would not have sufficient constraining species quota to mitigate the risk of exceeding quotas. However, a large risk pool can lead to economic free-riding [20] and reduce incentives to fish selectively and pool quota [28]. The Amendment 80 fleet in Alaska is one example of a risk pool that can enforce group norms, particularly vessels with high bycatch, to co-operatively avoid bycatch [1,2].

A number of factors that were not explicitly accounted for here may have affected the results. Conditions in the seafood market may alter the incentives to target certain species, and interactions between exclusivity and industry involvement were found to have the strongest effect on catch:TAC ratios [30] but were not accounted for here. Price data were compiled from the NOAA Commercial Fisheries Statistics database (http://www.st.nmfs.noaa.gov/commercial-fisheries/commercial-landings/annual-landings/index) to gain some sense of market conditions from 2008 to 2013. Revenues and landings for species from the West Coast fishery were compiled, and price per kilogram for nearly all species remained relatively unchanged from 2008 to 2013 (Fig. S2). Coastwide sablefish had a maximum value in 2011 (Fig. S2), but sablefish north and south catch:TAC ratios were near one in 2011 and generally high throughout 2008–2013. Prices per kilogram are a rough proxy for market conditions, but there may have been strong incentives to target sablefish selectively in 2011.

Both fisheries have undergone a number of management changes. For example, prior to catch shares in the West Coast fishery, discards were not managed and there were no TACs specific to the trawl sector. The calculated TACs represent an approximation, and West Coast fishers were not managed with hard

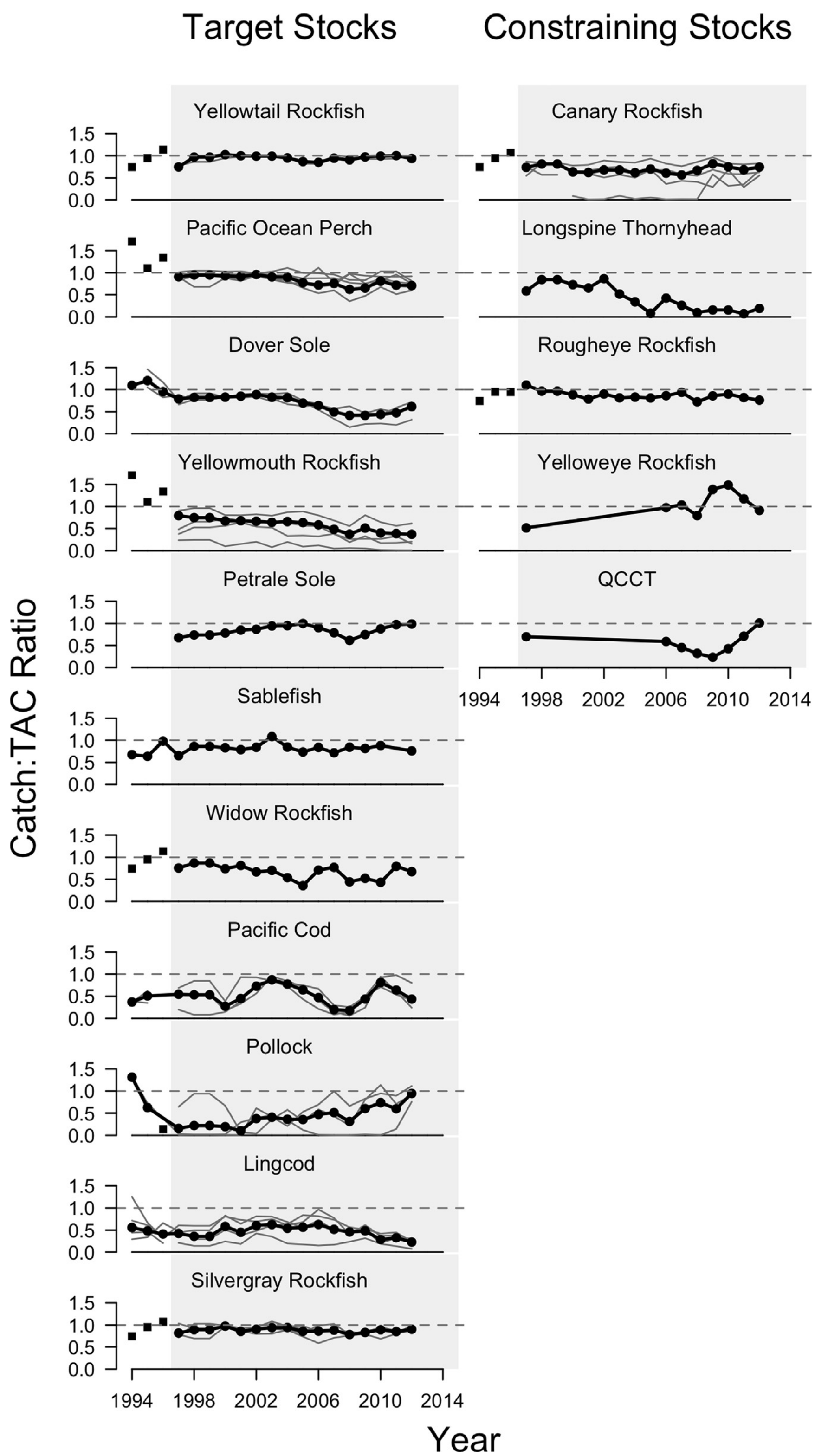

Fig. 8. Time series of catch:TAC ratios for both target and constraining species in the BC fishery. Catch shares were implemented in 1997, indicated by gray shading. Squares indicate years where stocks were managed as a complex. Gray lines indicate area-specific catch:TAC ratios and connected black points indicate average catch:TAC ratios across areas. The gap in the yelloweye and quillback, china, copper, tiger rockfish (QCCT) complex is due to years where landings were prohibited.

quotas. Changes in TACs would likely affect catch-quota balancing. In the West Coast fishery, TACs underwent decreases for sablefish, petrale sole, and canary rockfish (Fig. S3), but TACs in the BC fishery underwent less sharp declines (Fig. S3).

Assumptions about management may have affected the degrees of catch-quota balancing in each fishery. Fishers in the West Coast fishery and risk pool may have been adjusting to new management and additional restrictions from 2011 to 2013, so the data may not represent the limits of fishers' abilities. The distinction between target and constraining species in the BC fishery may not be well defined, which is perhaps one of the key differences between the two fisheries. The high degree of overall catch-quota balancing in the BC fishery is unaffected by species classifications.

5. Conclusion

In conclusion, it is clear from the results that catch shares will not result in perfect catch-quota balancing in multispecies fisheries, despite increased fishing flexibility, incentives for information sharing and cooperation, and transfer of quota. Specifically, there may be few policies to increase catch-quota balancing as TACs for constraining species become more limiting.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at http://dx.doi.org/10.1016/j.marpol.2016.05.010.

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