Marine Policy 55 (2015) 1–10

Contents lists available at ScienceDirect

Marine Policy

journal homepage: www.elsevier.com/locate/marpol

Catch-quota balancing mechanisms in the Icelandic multi-species demersal fishery: Are all species equal?

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ARTICLE INFO

Article history:
Received 25 July 2014
Received in revised form
11 January 2015
Accepted 11 January 2015

Keywords:
Catch-quota balancing mechanisms
Species transformations
Between-year quota transfers
Individual transferable quotas
Icelandic fisheries management
Total allowable catch

ABSTRACT

In this study, utilization of catch-quota balancing mechanisms in the Icelandic demersal fishery, which allow for individual transferable quota to be transformed among species and transferred between years, is analyzed to determine whether annual catches closely adhere to total allowable catches on average. Icelandic landings data for 14 demersal fish species during 2001–2013 are compared to implemented total allowable catches as well as catch limits recommended by the Marine Research Institute (MRI) and a proxy for annual market values. Landings surpassed legal limits of total allowable catch in 27% of the cases (landings by species by fishing year), mostly due to species transformations, but TAC overages were not consistent for any species. Instead, catches of some species were consistently less than legal limits, with some indications that landings were related to profitability (i.e. landings were correlated with market value). However, landings surpassed MRI recommendations in 67% of the cases, and landings of four species (Atlantic wolffish, haddock, monkfish and redfish) consistently exceeded MRI recommendations. Therefore, discrepancies between scientific recommendations for catch limits and quotas selected through the political process may represent a higher risk to long-term sustainability than catch-quota balancing mechanisms.

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1. Introduction

Reducing discards is a ubiquitous issue in the management of multispecies fisheries. Discarding behavior is incentivized whenever the quota of a species runs out before quotas of more profitable species have been caught [1]. “Catch-quota balancing” regulations in fisheries managed using individual quotas include a variety of measures designed to allow fishers to match quota holdings with their actual landings and hence avoid discards. Such regulations include quota trading and retroactive catch balancing, the ability to carry forward unused quota or borrow from the next year's allocation (“between-year transfers”), transformation of quota from one species into another, and the option to pay for catch that exceeds quota [2–4]. This study contributes to policy development of multi-species regulations aimed at reducing discards by documenting and analyzing the system of catch-quota regulations that are implemented in Iceland.

Iceland currently employs one of the most expansive sets of catch-quota balancing mechanisms, which includes between-year transfers, species transformations, and some leniency in penalizing over-quota landings, as well as quota trading [Table 1]. In the species transformation system, individual transferable quotas (ITQs) can be transformed from one species to any other species except Atlantic cod (*Gadus morhua*). Conversion rates are set according to “cod equivalents,” which are set based on market prices (relative to cod) during the previous year. Although species transformation regulations, as they are implemented in Iceland, include limitations, they could still lead to the risk of exceeding total allowable catches (TACs) of low-abundance species. Nonetheless, species transformations have been used in some form in Iceland since 1991 (http://www.reglugerd.is/), yielding a long history of stable usage since the ITQ system was expanded to virtually all Icelandic fisheries [5].

The Icelandic species transformation system is of particular interest to managers and scientists outside of Iceland because they explicitly address the multi-species nature of the demersal fishery as a joint production problem. The regulations allow for flexibility when it is not possible or costly to match species composition to quotas. Similar systems have been or are currently used in other

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http://dx.doi.org/10.1016/j.marpol.2015.01.004
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Table 1
List of major catch-quota balancing mechanisms used in Iceland (Icelandic Fisheries Management Act no. 38/1990 and subsequent amendments; see http://www.fisheries.is/management/fisheries-management/the-fisheries-management-act/ for English translation, last accessed 25. October 2014).

Mechanism	Regulations and limitations
Between-years transfers	Carry-forward: unused quota can be transferred to next year up to a maximum of 15% of species quota before trade and adjustments. Carry-backward: Exceeded quota can be borrowed from the next year up to a maximum of 5% of species quota before trade and adjustments
Species transformations	Exchange rates ("cod equivalents"): based on a species previous year's market value relative to cod (where cod = 1). One-way cod transformations: No species can be transformed into cod, but cod can be transformed into other species. No more than 5% total quota cod equivalent value can be exchanged. No more than 1.5% total quota can be transformed into a single species
Grace take	5% over a species quota can be landed after using catch-balancing mechanisms, but it must be auctioned. 20% of earnings are kept; the other 80% are forfeit to the Directorate of Fisheries. Referred to as "grace take" for this study
Surrender	If landings of a species exceed the grace take limit, 100% of its revenues are billed by the Directorate of Fisheries and there is risk of license revocation
Other	Permanent trade of catch shares and annual leases of quota allowed. Day-trip long-line vessels can land up to 16% over their quota of cod, haddock, or wolffish

fisheries (e.g. past use in the New Zealand ITQ system, present multiuse provisions in the ITQ system for US Gulf of Mexico Grouper-Tilefish that allow a portion of the red grouper [*Epinephelus morio*] quota to be harvested under gag [*Mycteroperca microlepis*] quota [US Code of Federal Regulations 50 CFR Part 622]). In addition, most ITQ systems include quota stocks that are species aggregates, effectively allowing unlimited transformation of quota between the species within a quota aggregate.

Furthermore, these regulations are applied across fishing gears and fleets, thereby linking resource users. In addition, the flexibility in matching catches to quotas is appealing to fishers. As a result, the intended purpose of reducing discards appears to have been achieved (yielding the idea that the catch-quota regulations are "successful"), as the discard ban in Iceland is thought to have high compliance [6]. Successfully implementing a discard ban is an important current issue in fisheries management (for example through fully documented fisheries [7]), as implementation of a discard ban is currently underway in the EU Common Fisheries Policy [8,4], among other locations.

However, the success of any fisheries management plan hinges critically on its ability to produce intended results and enforce regulations. Most nations that have implemented species transformation systems in a more limited manner have eventually removed them [2]. The additional flexibility yields legal routes for TACs to be exceeded, and therefore the potential for landings to consistently exceed catch limits. Although regulations are only intended to allow landings to fluctuate evenly around the TAC, in some cases they have not. Therefore, purpose of this study was to evaluate how well the species transformation system in Iceland currently achieves the goal of allowing landings to fluctuate around catch limits without the TACs of some species being consistently exceeded or left unfilled. To do this, fisheries landings data were analyzed across the fourteen demersal fish species included in the Icelandic species transformation system [Table 2]. Landings data were studied in relation to both the regulatory limits of total allowable catch and the recommendations of the Marine Research Institute (MRI), the latter of which may have more biological relevance. Landings were also assigned to catch-quota balancing mechanisms (i.e. species transformations and between-year transfers) to analyze how each regulation contributes to these patterns. Finally usage of these mechanisms was related to a proxy for relative annual market value among species to determine whether regulation usage was economically driven.

Table 2
Species composition in demersal stock landings by weight (fishing years 2001–2013) and revenues (calendar years 2001–2012).

Species		% Total Catch	% Total Revenue
Common name	Scientific name		
Atlantic cod	*Gadus morhua*	41.1	47.1
Atlantic wolffish	*Anarhichas lupus*	3.3	2.7
Common dab	*Limanda limanda*	0.4	0.2
European plaice	*Pleuronectes platessa*	1.5	1.5
Greenland halibut	*Reinhardtius hippoglossoides*	3.6	6.7
Haddock	*Melanogrammus aeglefinus*	16.5	15.3
Lemon sole	*Microstomus kitt*	0.5	0.8
Ling	*Molva molva*	1.5	1.0
Long rough dab	*Hippoglossoides platessoides*	0.2	0.1
Monkfish	*Lophius piscatorius*	0.6	1.3
Redfish	*Sebastes* spp.	15.9	15.2
Saithe	*Pollachius virens*	13.2	7.3
Tusk	*Brosme brosme*	1.3	0.6
Witch flounder	*Glyptocephalus cynoglossus*	0.4	0.3

2. Methods

2.1. Data sources

In the Icelandic demersal fishery, total allowable catch quotas are determined by the Ministry of Fisheries each year for fourteen species based on, but not necessarily exactly following, recommendations from the MRI. Total quotas are then distributed among the quota holders as ITQs. In general, catches must be balanced with quota, but the catch balancing system includes a number of mechanisms that allow individuals to balance catches in excess of quota holdings [Table 1]. Publicly available landings data were used from the Icelandic Directorate of Fisheries (www.fiskistofa.is) for the fishing years 2001 to 2013 and total revenue data from Statistics Iceland (www.statice.is) for 2001–2012 (data for 2013 were not available) to evaluate the correspondence of total catches with the total quotas and MRI recommendations. Each fishing year runs from 1 September to 31 August, and is indicated in a two-year format on the website (e.g. 2012/2013), but in this study notation refers only to the last year of the two-year period (e.g. 2013). For each year, the website indicates determined quotas and any adjustments to these quotas, catches and how they were accounted for (see below). Most accounting is detailed by vessel, but for this study the annual totals within the Icelandic EEZ were used (summed across vessels). Reported annual species conversion rates are also used ("cod equivalents"), which are calculated based on mean market prices of both catch and quota from the previous year. Cod equivalents represent two distinct pieces of information: (1) conversion rates for the present year (CR), and (2) an index of market value for this year (MV, which is equal to CR in the next year). Recommended total allowable catch quotas (RTACQs) were obtained from the MRI annual reports [9] after correction for gutting using species-specific ratios of gutted to non-gutted weights (the data from the Directorate of Fisheries are in gutted weights). Gutted to non-gutted ratios were calculated by dividing allocated quotas from the Directorate website by allocated quotas from the MRI reports.

The goals of our analysis rely on an ability to attribute catch quantities not only to the total allowable catch but also to mechanisms surrounding its implementation, e.g. between-year transfers and species transformations. Although these mechanisms are used simultaneously and at different rates among vessels, this study focuses on their aggregate effect on the fishery across vessels and fleets. Therefore, the total catches are partitioned among potential mechanisms based on the accounting hierarchy defined by the Fisheries Directorate, which applies both across the fishery and by individual vessels. That is, when a vessel lands a certain amount of catch, that catch is accounted for in the following order: by (1) applying its quota defined by its quota share, (2) adding special permit quantities (which are generally very small and address various socioeconomic mandates), (3) applying annually leased quota among vessels, (4) adjusting this status by any between-year quota transfers from the previous year, (5) applying species transformations, (6) adjusting the status by allowable between-year quota transfers applicable to *this* year, and (7) classifying any leftover quota as unused or unaccounted for catch as penalizable overcatch. This hierarchical structure allowed for classification of catch as accounted for by each regulation, up to the maximum amount allowed for that regulation. That is, any catch landed by a fisher is first accounted for as filled quota (1), plus filled special permits (2), plus or minus between-boat transfers in quota (3) or any quota transferred from the previous year (4). However, if there is no catch in excess of the sum of 1–3, transfers in quota from the previous year were never used, so catch assigned as a result of the between-year regulation equals 0. If a backward transfer occurred instead (i.e., from this year to the previous year due to excessive fishing in the previous year) and catch equals or exceeds the sum of 1–3, then catch assigned as a result of between-year transfers is negative.

Catch in excess of the sum of 1–4 is assigned to be a result of species transformations (5). In common with between-year transfers, the catch assigned to species transformations can be negative when quota of a species has been transformed into another species. In the instances where catch can go negative (4 and 5), our definition of “catch” is effectively a usage of quota that is assigned to a given regulation, rather than actual landings. The final steps in the accounting hierarchy are not used in the following analyses (6 and 7), although note that applying *this year's* between-year transfers in step 6 will define the quantities calculated in step 4 of next year's accounting. Based on this hierarchy, the catch and quota quantities listed in Table 3 were used as data for the following analyses.

2.2. Indices

To analyze how landings (i.e. total catch) deviated from the total allowable catch allocated by the Ministry of Fisheries, percentage difference between landings (i.e. total catch, TC) and total allowable catch (i.e. total quota, TACQ) was calculated for each species s in each year t:

$$\%(\text{TC–TACQ})_{s,t} = \frac{\text{TC}_{s,t} - \text{TACQ}_{s,t}}{\text{TACQ}_{s,t}} \times 100 \tag{1}$$

To analyze how actual landings deviated from the total allowable catch as recommended by the Marine Research Institute, percentage difference between landings (TC) and recommended total allowable catch (RTACQ) was calculated for each species-year combination:

$$\%(\text{TC–RTACQ})_{s,t} = \frac{\text{TC}_{s,t} - \text{RTACQ}_{s,t}}{\text{RTACQ}_{s,t}} \times 100 \tag{2}$$

The measures $\%\ \text{TC}-\text{TACQ}$ and $\%\ \text{TC}-\text{RTACQ}$ both reflect variation in total catch, but they reference different quantities for each species. If variation in total catch were random and normal, catches in year t should exceed TACQs in roughly 50% of the total number of years z. To analyze the deviation from this expectation of 50%, the percentage years with TC exceeding TACQ or RTACQ (centered around 0%) were calculated as

$$\%Y_{\text{TC}>\text{TACQ}} = \frac{\sum_{t=1}^{z} y_t}{z} \times 100 - 50 \tag{3}$$

$$\%Y_{\text{TC}>\text{RTACQ}} = \frac{\sum_{t=1}^{z} y_t}{z} \times 100 - 50 \tag{4}$$

where y_t=1 if TC > TACQ in Eq. (3) or if TC > RTACQ in Eq. (4), and 0 otherwise.

To analyze usage of previous year transfer mechanisms, percentage catch accounted for by previous year transfers was calculated as

$$\%\text{PYT}_{s,t} = \frac{\text{PYC}_{s,t}}{\text{TC}_{s,t}} \times 100 \tag{5}$$

where PYC indicates catch transferred from (negative) or to (positive) the current year.

To analyze usage of species transformation mechanisms, percentage catch accounted for by species transformations was calculated as:

$$\%\text{SPT}_{s,t} = \frac{\text{STC}_{s,t}}{\text{TC}_{s,t}} \times 100 \tag{6}$$

where $\text{STC}_{s,t}$ indicates catch transformed from (negative) or to (positive) the focal species s.

2.3. Analyses

For each species, it was tested whether the mean percentage difference between TACQ and total catch ($\%\ \text{TC}-\text{TACQ}$) differed significantly from zero to determine whether some species were consistently caught under or over the TACQ in the time period analysed. To do this, t-tests were used for each species, resulting in

Table 3
Description of data extracted or calculated for analyses, either from Marine Research Institute reports [4] or the Fisheries Directorate webpage (www.fiskistofa.is). Note that quota quantity variables end in Q whereas catch quantities end in C.

Variable	Description
CR	Cod equivalent conversion rates from this year
MV	Cod equivalent conversion rates for next year (proxy for market value)
RTACQ	Total allowable catch quota recommended by the Marine Research Institute
TACQ	Directly reported total allowable catch quota + special permit quota
PYQ	Quota adjustments due to between-year transfers from the previous year. Directly reported and can be positive or negative
TC	Total catch
PYC	Catch accounted for by previous year transfers: calculated as 0 if TC < TACQ; otherwise the minimum of PYQ and TC − TACQ. Can be negative if PYQ is negative
STC	Catch accounted for by species transformations: directly reported and can be negative, 0, or positive up to certain limitations [Table 1]

fourteen tests. To control for Familywise error rate in multiple comparisons, significance was tested using a Bonferroni–Holm adjustment to $\alpha=0.05$ (i.e., reported p-values are not adjusted but significance tests are). The same analysis and α-adjustment was conducted for the mean percentage difference between recommended catch limits and total catch (% TC − RTACQ). Binomial tests were used to test whether the number of years with total catch exceeding allocated quota (% $Y_{TC>TACQ}$) or exceeding recommended TACs (% $Y_{TC>RTACQ}$) differed from 50%. Again $\alpha=0.05$ was adjusted in each of the fourteen significance tests, one for each species within each variable tested, using the Bonferroni–Holm method.

The measures % PYT, % SPT, and their sum (% PYT + % SPT) were then tested for differences from 0 using t-tests, to determine whether justifications for species landings differed in regulation usage. Linear models predicting % TC − TACQ or % TC − RTACQ with either % PYT or % SPT as the predictor variable, i.e. four linear model types, were used for each species to determine which mechanisms contributed to variation in total catch. Both t-tests and linear models used Bonferroni–Holm adjustments to $\alpha=0.05$ in each of the fourteen significance tests, one for each species within each analysis (linear model type or t-test series). Finally, two linear models, one predicting total catch (as % TC − TACQ) and the other predicting usage of species transformations (% SPT), were run including market value as a linear predictor, species as a factor, and their interactions. These last tests were used to examine effects of economic incentives (i.e., higher market value) on total catch and species transformation usage, and how these effects differed by species.

3. Results

3.1. Systematic deviations in landings from allocated total allowable catches

Demersal Icelandic fisheries are dominated by cod (∼50% in both landings and revenue), haddock (∼15% in both), a quota basket of redfish species that only recently has been managed as separate species (∼15% in both), saithe (∼13% landings, ∼7% revenue), and Greenland halibut (∼4% landings, ∼7% revenue) [Table 2]. Over the time period analysed, no species were consistently caught over the TACQ. However, catches of common dab and long rough dab were consistently less than the TACQ [Figs. 1 and 2]. The percentage difference in TC from TACQ were characterised by high interannual variability in all species except Atlantic cod and haddock [Fig. 1]. Overall, landings surpassed the TACQ in 27% of the cases (species by fishing year). Two species, ling and lemon sole, were caught over the TACQ in more than 50% of the years [Fig. 2]. Ling and lemon sole were caught respectively 14% and 12% above the TACQ on average [Fig. 2], with maximum values of 37% and 51%, respectively [Fig. 1].

Four species (haddock, monkfish, redfish and Atlantic wolffish) were consistently fished above the RTACQ over the time period, while long rough dab was consistently caught under the RTACQ [Fig. 2]. The percentage difference of TC from RTACQ had high interannual variability for most species [Fig. 1]. Catches surpassed the RTACQ in 67% of the cases. All species except common dab, long rough dab and Greenland halibut were caught over the RTACQ more than 50% of the years [Fig. 2]. Redfish, monkfish and Atlantic wolffish had the greatest difference between TC and RTACQ, being caught respectively 76%, 27% and 22% above the RTACQ on average [Fig. 2]. Interestingly, while differences between catches and the RTACQ were not statistically significant for some species, they were nonetheless positive and high in some years. For example, Greenland halibut and lemon sole were caught respectively 30% and 25% above the RTACQ on average [Fig. 2], with maximum values of 210% and 88%, respectively [Fig. 1].

3.2. Differences among species in usage of catch-quota regulations

Percentage of the catch accounted for by previous year transfers (% PYT) fluctuated between 0 and 14% [Fig. 1], with significant mean forward transfers of catch for ling and Atlantic wolffish [Fig. 3]. Percentage of the catch accounted for by species transformations fluctuated between −709% and 37% [Figs. 1 and 4], with negative versus positive values indicating transformations away from versus into a species. Note that extreme percentages can be obtained, as they are here, when actual catch in the denominator is small as compared to regulation usage. The flatfish species seemed to generally have the largest amount of quota (as a percentage of catch) transformed into other species (except European plaice and lemon sole), whereas species such as ling, tusk and wolffish often had a large percentage of its catch attributed to species transformations [Fig. 4]. Note also that the larger the stock, the smaller the percentage of catch can be accounted for by species transformations due to limitations [Fig. 4]. Both mean percentage of catch accounted for by species transformations (% SPT) and the sum of species transformations and previous year transfers (% PYT + % SPT) were significantly greater than zero for ling and significantly less than zero for common dab and long rough dab [Fig. 3].

Previous year transfers had a significant effect on differences in total catch from TACQ for five species (cod, haddock, redfish, monkfish, and saithe), while species transformations had an effect for all species except Atlantic cod and haddock [Table 4]. Previous year transfers had no effect on difference in total catch from recommendations (RTACQ), while species transformations had an effect for three species only (European plaice, lemon sole, and tusk). All significant effects (i.e. coefficient estimates in Table 4) were positive, indicating that higher fishing levels corresponded with more usage of both catch-quota balancing mechanisms (previous years transfers and transformations into the considered species).

3.3. Role of market value in usage of catch-quota balancing regulations and deviating from the TACQ

In the linear model predicting deviation in total catch from TACQ and including all species, significant interactions were found that indicated an increase in total catch with market value (MV) for four species: European plaice, Greenland halibut, long rough dab, and witch flounder ($F_{26,149}=16.78$, $P<0.0001$) [Table 5]. Only long rough dab showed a significant interaction in the linear model predicting species transformation usage (%SPT) with species and MV ($F_{26,149}=6.208$, $P<0.0001$) [Table 5]. Therefore, although a general relationship between market value and total catch could be detected for the four species listed, it could only be linked with greater species transformation usage for long rough dab.

4. Discussion

4.1. Systematic deviations from catch limits under catch-quota balancing regulations

In any mixed fishery, ensuring that TACs are adhered to remains problematic when individual species quotas become limiting, thereby incentivizing discards. By adding flexibility to Icelandic regulations controlling how quotas may be used by fishers, the constraints of single species quotas are alleviated.

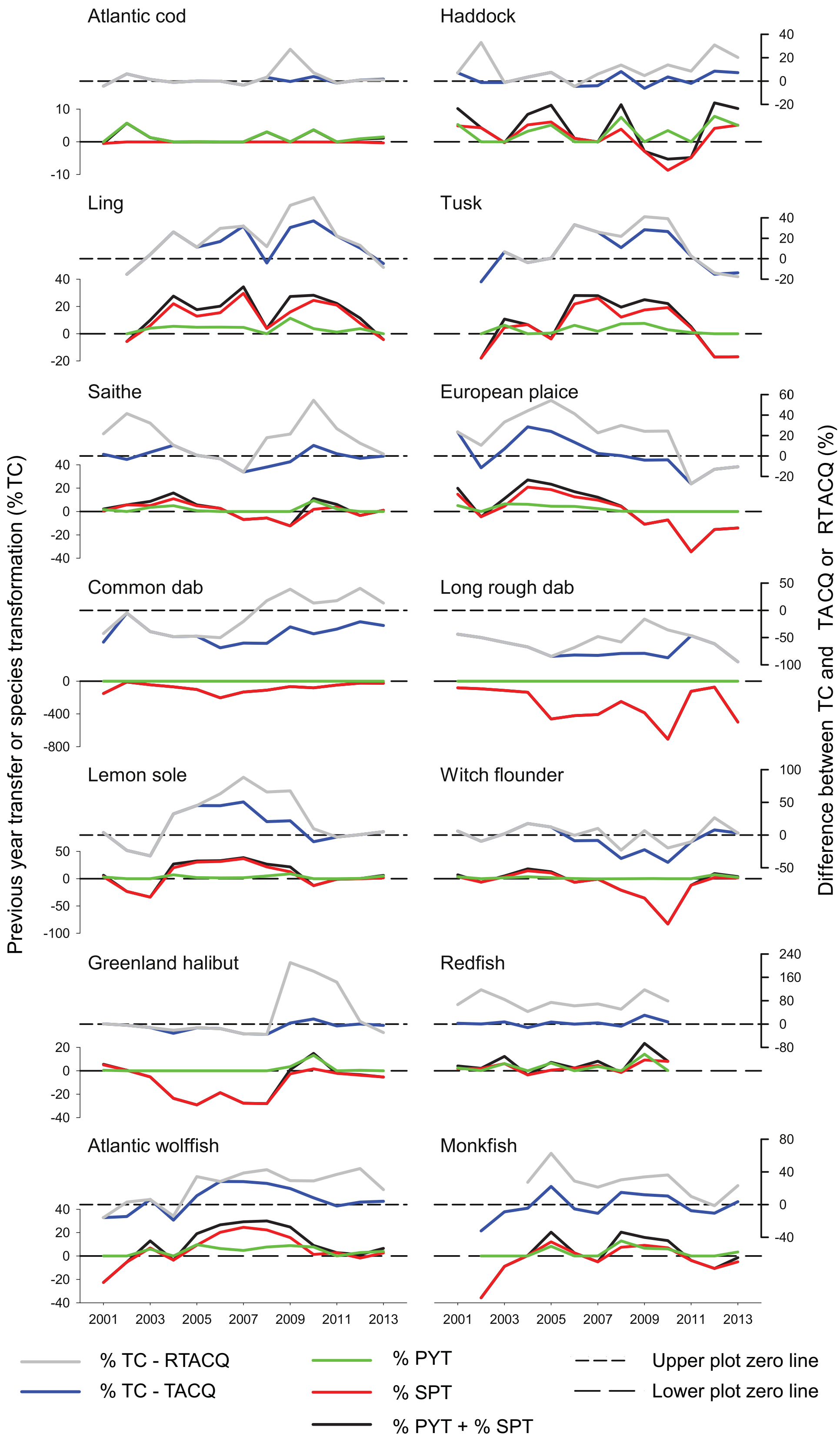

Fig. 1. Each species panel is composed of two plots of time series, the top of which shows deviation in annual landings from actual or recommended catch limits (right *Y*-axes), and the bottom of which shows catch-quota balancing mechanism usage (left *Y*-axes). In left *Y*-axes, previous year transfer and species transformation usage are shown as a percentage of total catch (% PYT or % SPT respectively). Positive % indicates increased catch due to the regulation (quota transformed into that species or transferred from the previous year); negative % indicates quota was removed (quota transformed into other species or transferred to the previous year). In right *Y*-axes, differences between total catch (TC) and the quota recommended by the Marine Research Institute (RTACQ), or total catch (TC) and the quota actually set by the Minister of Fisheries and (TACQ), are shown as a percentage of the quota indicated (% TC – RTACQ or % TC – TACQ respectively). Lines representing 0%, indicating no regulation usage for the top plot or no deviation from total quotas for the bottom plot, are shown as "zero lines".

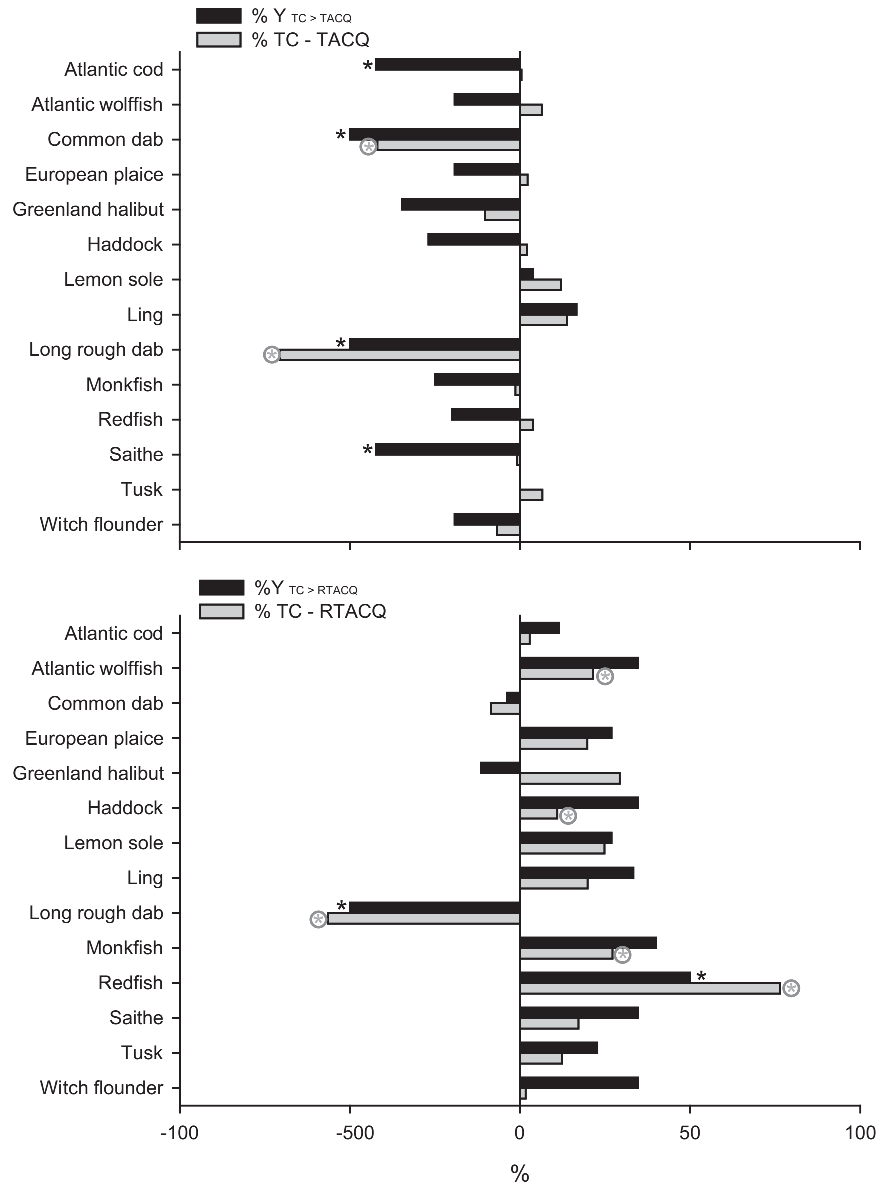

Fig. 2. Deviation from 50% in percentage of years with total catch (TC) exceeding Marine Research Institute recommendations (% $Y_{TC>RTACQ}$, bottom panel) or exceeding catch limits set by the Minister of Fisheries (% $Y_{TC>TACQ}$, top panel) are shown as black bars. Differences between total catch (TC) and the quota recommendations (RTACQ), or total catch (TC) and the quota actually set by the Minister of Fisheries and (TACQ), are shown by grey bars as a percentage of the quota indicated (% TC − RTACQ in bottom panel, or % TC − TACQ in top panel). Mean values that significantly differed from zero over the time period, as tested with binomial tests (% $Y_{TC>TACQ}$ and % $Y_{TC>RTACQ}$) or *t*-tests (% TC − TACQ and % TC − RTACQ) and a Bonferroni–Holm adjusted α, are indicated by black or encircled grey stars.

The resulting reduction in discards should increase efficiency of stock utilization. However, the increased flexibility generated by catch-quota balancing regulations may also allow for greater risk of stock depletion due to persistent surpassing of catch limits. For example, as limitations to species transformations in the Icelandic system are based on percentages of total quota holdings, which includes the very large cod stock, it is legally possible to surpass total allowable catches of small stocks by several hundred percent [Fig. 1], which would not be in line with the goals of the Icelandic Fisheries Management Act, whose main objective is "to promote… conservation and efficient utilization [of exploitable marine stocks of the Icelandic fishing banks]" (Act no. 38/1990 and subsequent amendments; see http://www.fisheries.is/management/fisheries-management/the-fisheries-management-act/ for English translation, last accessed 25 October, 2014).

Therefore, despite the apparent reduction in discards, the Icelandic management system would not be considered "successful," if its regulations or a lack of enforcement led to overexploitation. However, judging success also requires knowledge regarding whether the stock assessments upon which TACs are based are reasonably accurate, as well as an indication within the policy regarding how acceptable stock status levels are across various species. For example, if a bioeconomic optimum is the goal of a multispecies fishery, desirable catch limits may be higher than those expected to attain MSY for some species, if this higher level allows for more efficient utilization of more profitable species. Acceptable limits are therefore highly context-specific. However, they are also difficult to define when insufficient data are available for biomass estimation. Therefore, success can only occur after (1) an acceptable limit is defined to create a TAC, (2) the stock assessment accurately provides the scientific basis to set the TAC, and (3) the TAC is adhered to.

To address the first criterion, acceptable biomass limits are generally recommended by the Icelandic Marine Research Institute using MSY as a target for setting catch limits (often with a buffer

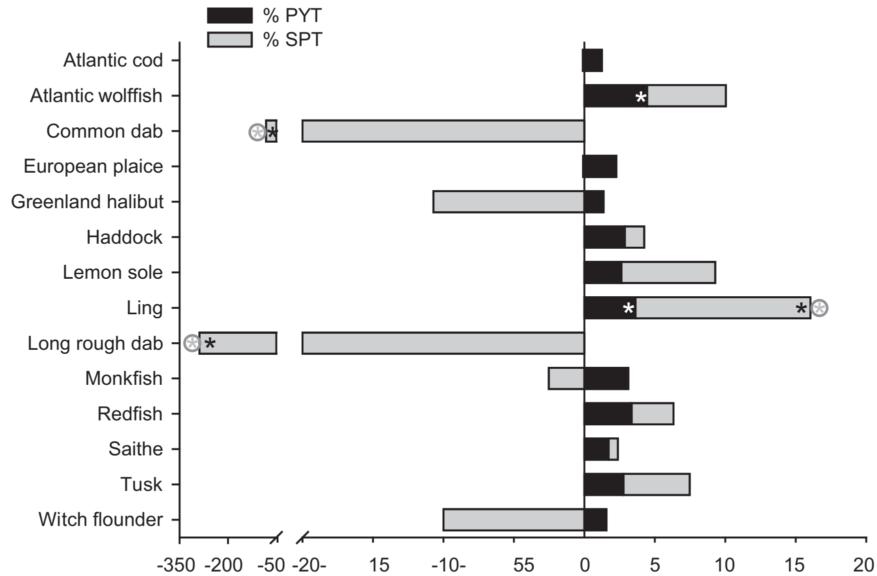

Fig. 3. Mean previous year transfer (% PYT) and species transformation (% SPT) as percentage of the total catch for each species. Mean values significantly different from zero over the time period, as tested with *t*-tests and a Bonferroni–Holm adjusted α, are indicated with white, black and encircled grey stars for % PYT, % SPT and % PYT+% SPT respectively. Positive % indicates increased catch due to the regulation (quota transformed into that species or transferred from the previous year); negative % indicates quota was removed (quota transformed into other species or transferred to the previous year).

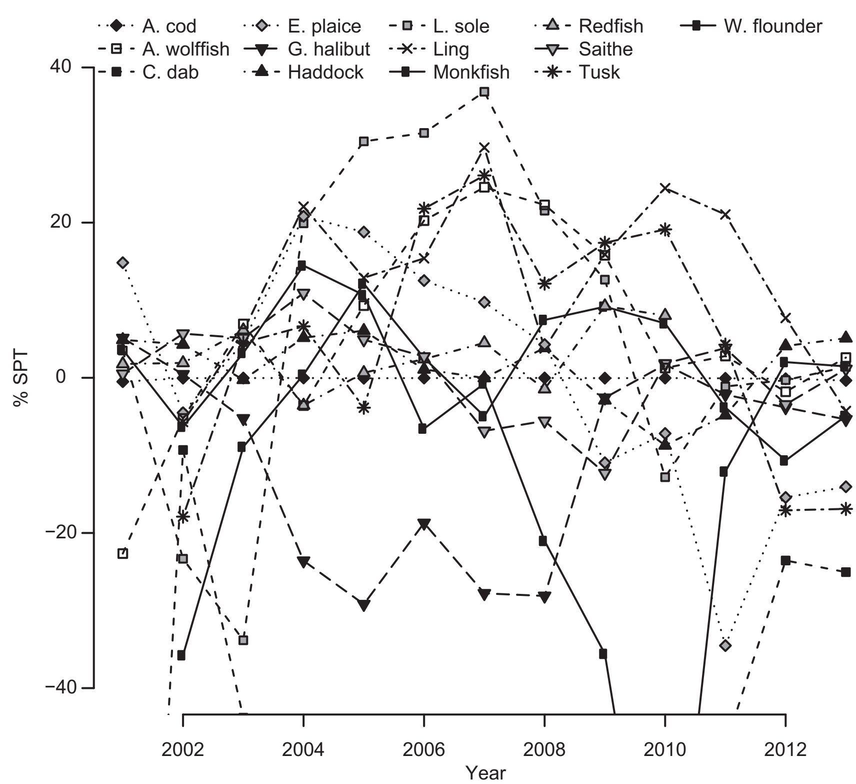

Fig. 4. Species transformation usage as a percentage of total catch (% SPT) as a comparison of usage magnitude across species. Values of 0% indicate no regulation usage. Positive values indicate increased catch due to species transformations. Negative values indicate transformations of quota into other species. Values more negative than those shown in this plot range can be seen in Fig. 1 for common dab, witch flounder and long rough dab. Long rough dab is not shown because all values are more negative than the plot range.

based on the precautionary approach [6]). However, not all stocks have biomass estimates from which MSY can be estimated. Currently, five of the largest Icelandic commercial demersal stocks (counting redfish as a quota basket) are evaluated by ICES, whose advice is generally followed when setting TACs. However, only three of these stocks had sufficient data to estimate biomass in the time range analyzed. The spawning stock size of the Icelandic cod is currently the highest it has been since the 1960s. Although stock assessments of the other two data-rich species (saithe and haddock) are uncertain due to large fluctuations in biomass indices, fishing mortality of all cod, saithe and haddock is estimated to be relatively low in recent years. Spawning biomasses are expected to grow or remain high as harvest control rules are implemented for saithe and haddock in the coming years [6]. Although some bias can be seen in

Table 4
Effects of previous year transfer (% PYT) and species transformation (% SPT) on the difference between TC and TACQ or RTACQ (% TC – TACQ or % TC – RTACQ), as tested with linear models (one for each species × predictor combination) with Bonferroni–Holm adjusted α for multiple comparisons among species (14 tests for each predictor variable). Significant *p*-values are indicated as * < 0.05 or ** < 0.001. Positive coefficient estimates (Est.) indicate that increases in total catch are associated with increases in usage of the catch-quota balancing mechanism. Standard errors of the estimates (S.E.) are shown.

Species	% TACQ – TC				% RTACQ – TC			
	% PYT		% SPT		% PYT		% SPT	
	Est.	S.E.	Est.	S.E.	Est.	S.E.	Est.	S.E.
Atlantic cod	1.3394	0.206**	4.1489	2.5653	0.5506	1.349	13.3935	16.7993
Atlantic wolffish	1.3241	0.6527	0.8921	0.1802*	0.9652	1.7119	0.9044	0.4727
Common dab	–	–	0.2923	0.0411*	–	–	0.3269	0.1547
European plaice	1.7219	0.8445	0.7486	0.1404*	−0.4409	2.0438	1.3822	0.3398*
Greenland halibut	1.4604	0.586	0.8935	0.1709*	13.365	5.3533	2.1021	1.5614
Haddock	1.6105	0.1966**	0.0963	0.1318	1.4239	1.2141	0.133	0.8144
Lemon sole	0.0356	0.5232	1.2053	0.0713*	1.9575	1.8436	1.4795	0.2513*
Ling	1.281	0.5054	1.2057	0.1448*	2.4389	1.3292	1.2567	0.3808
Long rough dab	–	–	0.0713	0.0123*	–	–	0.0065	0.0298
Monkfish	1.3552	0.3169*	0.7759	0.1091*	−0.5124	0.9572	2.2414	0.5907
Redfish	1.4567	0.2491*	1.4019	0.2829*	1.4536	1.7933	3.0545	2.037
Saithe	1.4902	0.4306*	0.5598	0.1933*	4.2942	1.904	−0.205	0.8547
Tusk	1.0292	0.7144	1.0104	0.1431*	1.9437	1.0146	1.0498	0.2189*
Witch flounder	2.6748	1.1176	0.5036	0.0962*	3.6774	1.3692	0.2026	0.1179

Table 5
Effects of market value (MV), species as a factor variable, and their interactions in linear models used to predict the difference between TC and TACQ (% TC – TACQ) or species transformation usage (% SPT). Significant *p*-values are indicated as * < 0.05 or ** < 0.001. Positive interaction estimates (Est.) indicate a steeper slope of market value to predict the dependent variable for the indicated species in comparison to the baseline (Monkfish). Standard errors of the estimates are shown (S.E.).

Predictor variables	**%TC-TACQ**			**%SpT**		
	Est.	**SE**	**P**	**Est.**	**SE**	**P**
Intercept	58.681	41.036		57.242	166.713	
Market value (MV)	−34.956	23.763		−34.798	96.539	
Common dab	−85.065	43.747		−74.069	177.726	
Atlantic cod	−23.271	18.051		−22.547	73.333	
Haddock	−60.815	46.411		−58.348	188.547	
Greenland halibut	−109.805	45.756	*	−87.024	185.886	
Ling	7.292	46.726		−12.256	189.828	
Long rough dab	−149.881	43.675	**	−486.492	177.433	*
Lemon sole	−42.246	50.643		−34.089	205.742	
European plaice	−105.729	44.977	*	−110.094	182.721	
Redfish	−82.707	50.297		−69.602	204.336	
Saithe	−63.700	43.814		−53.894	177.997	
Tusk	11.332	48.153		1.994	195.625	
Witch	−159.592	58.141	*	−136.014	236.202	
Atlantic wolffish	−49.142	50.547		−37.860	205.353	
MV*Common dab	−6.664	45.769		−139.347	185.938	
MV*Haddock	39.525	33.442		37.542	135.862	
MV*Greenland halibut	56.507	25.955	*	44.843	105.444	
MV*Ling	−49.836	42.896		−18.242	174.268	
MV*Long rough dab	92.550	46.542	*	426.182	189.079	*
MV*Lemon sole	31.821	31.671		23.047	128.665	
MV*European plaice	85.144	29.974	*	88.520	121.772	
MV*Redfish	84.315	56.005		61.878	227.524	
MV*Saithe	43.105	37.496		29.526	152.329	
MV*Tusk	−121.860	65.867		−100.171	267.590	
MV*Witch	189.094	71.182	*	147.395	289.184	
MV*Wolffish	30.691	46.449		15.951	188.704	

stock assessments through retrospective analyses, the bias is not consistently positive or negative, and is taken into account when possible before recommendations are given [10]. Therefore, stock assessments of these three species are considered trustworthy by external reviews, and stock assessments of the other two data-poor stocks (Greenland halibut and various redfish stocks) have been evaluated as the best possible options given data constraints [6]. These reasonably accurate stock assessments fulfill the second criterion. However, the remaining stocks included in this study are data-poor and not evaluated by ICES, precluding the definition or estimation of acceptable limits (criteria 1 and 2). Therefore, the only judgement of success possible across all species is to determine whether TACs are adhered to (criterion 3).

To address the third criterion, our results suggest no consistent surpassing of total allowable catches between 2001 and 2013 for any species, indicating that the outcome of implementing catch-balancing regulations is still in line with current implementation of the Icelandic Fisheries Management Act. Instead, the mean total catches were close to or less than the total allowable catches for most species in most years [Fig. 2]. The exceptions included ling and lemon sole, the landings of which exceeded catch limits by 14% and 12% on average, although not significantly. As both ling and lemon sole are data-poor stocks and show either decreasing juvenile biomass (for ling [10], despite increasing index of exploitable biomass [9]) or relatively high fishing mortality (lemon sole: [9]), a precautionary approach seems prudent.

Total landings were highly variable in most cases, indicating two important caveats to our analysis: (1) the power in these analyses to detect systematic overfishing may have been low due to the limited time series of data, and (2) there could be other negative biological consequences associated with high fishing variability that are not captured by our analyses. That is, fishing for several consecutive years over allowable limits may have biological impacts. Lemon sole for example, was fished on average 36% over catch limits between 2004 and 2009 [Fig. 1]. However, although variation in landings may have negative biological impacts, it may also have positive economic impacts. Variation in landings is often indicated as a negative quality of a fisheries management system, as unpredictability leads to more financial risk for fishing businesses dependent on a stable economic return over time. However, as variation in the Icelandic system stems from greater flexibility of fishermen to respond to natural and/or market conditions rather than a top–down hierarchical structure of limitations, financial risk is actually likely reduced.

4.2. Adhering to scientific advice

Catch limits are often set above recommendations by fishery managers for socio-political reasons and concerns regarding accuracy of stock assessments [11,12], even though a vast and growing body of evidence suggests that this is not a sustainable practice [12–14]. Iceland's fishery management record is no exception to this pattern, except in the most recent few years, which have shown a decrease in the discrepancy between scientific recommendations and regulations [Fig. 1]. Iceland is one of the few nations that openly publishes historical recommendations versus regulations in an easily obtainable format [9], so that evaluations like this one are easily made.

Catch limits in Iceland are rarely set lower than scientific recommendations [9], but catch limits are set above these recommendations often enough to show a general pattern of fishing over recommendation levels for most species since 2001 [Fig. 2]. However, this was statistically significant for only four species (haddock, wolffish, monkfish, and redfish). In general, flatfish stocks still appear particularly vulnerable in Iceland to political increases in total catch limits from scientific recommendations (e.g. common dab and long rough dab [9]). In the case of common dab, the discrepancies between RTACQ and TACQ led to catches 24% higher than the RTACQ on average since 2008. However, these did not lead to systematic fishing over the recommendation levels, likely due to economic constraints (i.e. most flatfish are likely not profitable enough to fill catch limits in general or in every year). The consistent underutilization of long rough dab, even in relation to scientific recommendations, supports this [Fig. 2]. In contrast, two of the four species that were systematically caught over scientific recommendations, none of which were flatfish, generated some of the highest revenues of demersal species (haddock and redfish, Table 2). A third species had the highest per kg prices in the transformation system (monkfish, Table 2), indicating potentially high profits for certain fishing sectors.

Although justifications that could be used by a manager for increasing catch limits beyond scientific recommendations can only be speculated on, some likely ones include: (1) preventing constraints on fishing activities due to the premature filling of catch limits of a particular bycatch species (and hence discards), (2) allowing greater fishing on less profitable species as a ‘consolation prize’ when the quotas for more profitable species are reduced due to a decline in biomass, (3) preventing large changes in catch limits, (4) short-term avoidance of low per capita profits in the fishing sector as a whole, (5) a lack of confidence in scientific results [11], or (6) gaining political favor with voters in future elections [11]. The first and second justifications may explain high catch limits despite scientific recommendations for the less profitable species (e.g. flatfish and wolffish), as many of the recent discrepancies follow a drop in biomass and focus on less profitable species. The fourth and fifth justifications would more likely apply to the highly profitable species, indicating that these could be the cause for systematic surpassing of recommendations for haddock and redfish. However, this latter issue will become moot for some of the most profitable fisheries in Iceland as harvest control rules (HCRs) are expanded to haddock and saithe stocks [6]. However, redfish (deepwater redfish *Sebastes mentella* and golden redfish *S. marinus*) are still considered data-limited in Icelandic waters [9], as are wolffish and monkfish, preventing similar movements toward HCR implementation for these stocks. Despite this drawback, precautions would be prudent as signs of decline have been detected for deepwater redfish, and low recruitment levels have been documented in Atlantic wolffish and monkfish [9].

4.3. Are all species equal?

Generally, previous year transfers have been used to account for more ling and wolffish catch being transferred into the current year than away [Fig. 3]. More increases in ling catch have been accounted for as species transformations into the species rather than away [Fig. 3]. Common dab and long rough dab show the opposite trend in species transformations. Therefore, common dab and long rough dab can be categorized as consistent “source” species for excess quota in the Icelandic system, whereas ling is a consistent “sink” species. Furthermore, the only significant correlations of market value with total catch were positive and for similarly underutilized flatfish species (long rough dab, Greenland halibut, witch flounder, and European plaice), indicating that increased catches of these species opportunistically occur when they are more valuable. However, the absence of a link between catch accounted for by species transformation and market value in all other species indicates that the method for setting “cod equivalent” conversion rates is sufficient to prevent targeting of more valuable species beyond their catch limits. Likewise, the method for setting conversion rates according to market value appears to prevent high-price species from becoming consistent sources of excess quota for catching other species (due to greater cod equivalent conversion rates).

Both previous year transfer and species transformation regulations yielded increases in total catch in relation to set catch limits or recommendations. However, this does not mean that they consistently yielded catches exceeding catch limits. Ling appears to be the only species that may receive detrimental effects of catch-quota balancing mechanisms, as it both exceeds its set catch limits by the highest percentage (14%, albeit not significantly), and higher catches are directly related to greater use of previous-year transfers and species transformations [Table 4]. However, as ling catch recommendations have consistently increased over time [9], apparently no additional regulatory action is currently needed. Instead, this example may illustrate a beneficial quality of species transformations: it potentially allowed the flexibility for catch to more closely track increasing biomass than current biological data, thereby preventing any constraints due to a mismatch between biological knowledge and actual conditions. Unfortunately, the same cannot be said for wolffish, whose high percentage of catch due to forward-year transfers may be a consequence of recent declines in biomass. That is, if 15% of last year's quota is carried forward and the catch limits simultaneously decline by 25%, then this year's catch may actually be increased by 20%, which exceeds the 15% limit. Fortunately this problem is ultimately self-correcting if declines are not precipitous and management remains precautionary.

5. Conclusions

The multi-species, multi-user nature of the Icelandic demersal fishery is explicitly integrated into the management system through the large number of catch-quota balancing mechanisms and by managing essentially all major fishing sectors under the same system of broad flexibility. This type of system is in stark contrast to more highly compartmentalized fishery management systems, in which any regulations that add flexibility are restricted due to separation of regulations among fishing sectors and/or species. In the latter case, increased rigidity comes at the expense of potentially increased risk to the individual fisher (i.e. a reduced portfolio effect, [15]). On the other hand, decreased rigidity across the entire fishery results in potentially greater risk in sustainability of individual species, as there is less direct control in exact total landings across years. It is somewhat surprising that more negative effects of the species transformation system (i.e. more consistent surpassing of TACs for either valuable or highly catchable species) are not apparent in the Icelandic system. Instead, setting catch limits above those recommended by the MRI appears to be a more common and important reason for discrepancies between recommended and actual catch.

A few possible explanations may resolve the effectiveness of the species transformation system at remaining on average close to the set catch limits. First, diversity in both fishing sectors and species may be sufficient to ensure a diversity of interests and reduce any strong effects on an individual species. Second, environmental variability may reduce targeting capabilities and likewise reduce strong effects on individual species. Third, there may be some self-correcting mechanisms inherent in the system that prevents overexploitation of certain species. For example, undetected biomass reductions of a given species may simply allow for greater landings of species with undetected biomass increases, as excess quota from the first can be transformed into the second.

There are also a number of other aspects of the Icelandic management system that serve to limit overutilization. First, a variety of other regulations (e.g. marine protected areas, real-time area closures [6]) aid sustainability of exploited stocks. Second, as most demersal fish stocks are resident (i.e. not shared internationally), landings and biomasses are surveyed, and discard estimates are comparatively low (~10% or less [16,17,6]), the top-down hierarchical structure for monitoring fisheries appears to be competent. Third, in-season monitoring may buffer the system enough so that the limitations of the species transformation system are never tested. For example, regulating bodies may either shut down fisheries or prevent fishers from fishing when mid-season monitoring shows unexpected results (e.g. catch limits being approached faster than expected or fishers targeting species for which they have no quota). Finally, underutilization of many demersal species [Fig. 2] indicates that species transformations may not be used simply for economic reasons: they are not necessary in many cases if it is not profitable to fill catch limits. Although the Fisheries Management Act mentions “efficient” use of resources, no economic data are used to set TACs, which are generally set to reflect MSY. Not filling a catch limit under these conditions indicates that, at least in the short or medium term, it is too costly to target such species to the extent to which MSY is landed. However, if fishing activities increase, for example as a result of greater competition, negative impacts of species transformations may become more noticeable as excess quota becomes less available and more profitable species become more highly targeted. In this scenario, it may become problematic to have excess unused quota available from less profitable species, as this frees unused quota to be used to target profitable species.

Therefore, the jury is still out on how effective versus risky the implementation of species transformation systems is in general, although Iceland's implementation appears to effectively incorporate flexibility while fulfilling its overarching fishery management goals. In the implementation of multispecies fishery management, a species transformation system holds promise because it appears effective at reducing discards. Discard estimates for Iceland are relatively low even though individual transferable quotas have the potential to increase high-grading and discarding [1,6]. However, reducing the necessity for targeting individual species may run counter to ecosystem management by reducing incentives to improve specificity of fishing gear, avoid non-commercial species or sensitive habitats, or carefully choose fishing locations [1,18]. In addition, a lack of sufficient data to evaluate effects on population dynamics of most stocks included in the system could result in unexpected outcomes in the future. However, the unexpected outcomes may not necessarily be detrimental in the face of uncertainty: the system may simply allow fishers to track biomass changes more quickly than the stock assessment process, allowing for higher catches as biomass increases (similar to our results for ling). Therefore, species transformations appear to be a useful tool for integrating multi-species considerations into a fishery management system. However, current regulations and stock assessments as they are implemented in Iceland may need to be modified if such regulations are to be implemented in a fisheries management system that has ecosystem-based management among its goals.

Acknowledgements

This study is a product of the Nordic Centre for Research on Marine Ecosystems and Resources under Climate Change (NorMER, Project no. 36800), which is funded by the Norden Top-level Research Initiative sub-programme ‘Effect Studies and Adaptation to Climate Change.’ We would also like to thank an anonymous reviewer and staff at the Marine Research Institute, Fisheries Directorate, and Ministry of Fisheries and Agriculture of Iceland for helpful comments and direction.

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