Marine Policy 108 (2019) 103646

Contents lists available at ScienceDirect

Marine Policy

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

Alternative outcomes under different fisheries management policies: A bioeconomic analysis of Japanese fisheries

Kanae Tokunaga[a,*,1], Gakushi Ishimura[b], Shigehide Iwata[c], Keita Abe[d], Kazuhiko Otsuka[a], Kristin Kleisner[a], Rod Fujita[a]

[a] Environmental Defense Fund, USA
[b] Iwate University, Japan
[c] Tokyo University of Marine Science and Technology, Japan
[d] Norwegian School of Economics, Norway

ARTICLE INFO

Keywords:
Bioeconomic policy simulation
Fisheries management
MSY-based management
Data-limited stock assessment

ABSTRACT

Japanese fisheries are underperforming, with stock declines in some key domestic fisheries. This study examines tradeoffs between allowing current fishing mortality levels to continue versus adopting fishing mortality levels that are intended to maximize either yield or profitability in Japanese fisheries. Because stock status estimates exist for only 37 stocks in Japan, a data-limited model is used to estimate the maximum sustainable yield-based (MSY) reference points for 95 commercially exploited fish stocks using landing data from 1964 to 2015, representing 84% of Japanese landings. Future catch, biomass, and profits are simulated under two policy scenarios: (1) catch at MSY and (2) an economically optimal policy that seeks to maximize profits given the biomass level projected in each year. These scenarios were compared to a business-*as*-usual scenario in which current fishing mortality rates are maintained into the future. The results suggest that adopting an economically optimal fishery policy could reduce catches over the next two decades, but increase the total annual profits by 3.5-fold and biomass levels by 30% by 2065 compared with the business-*as*-usual scenario. In comparison, managing for MSY would require less of a short-term decrease in catch, but ultimately result in much lower profits. While these simulations do not account for real-world constraints that may limit implementation of these alternative policies, this analysis is important because it illustrates the tradeoffs and potential fishery upsides possible through fishery management reforms.

1. Introduction

Japan is one of the most important fishing countries both in Asia and globally. It is responsible for the fifth largest fisheries production volume in the world and three of the 16 largest seafood companies are based in Japan [1,2]. As of 2016, the fisheries production sector employed 160,000 people and the production value of marine capture fisheries amounted to over 962 billion Japanese yen.[2] Japanese offshore and distant-water fisheries are mainly managed by limited entry licenses, while coastal fisheries are managed under territorial use rights [3–5]. Although total allowable catch limits (TACs) were introduced in 1997, they are only set for eight stocks out of 113 [6–8]. Currently, only Southern bluefin tuna, Atlantic bluefin tuna, and red snow crab fisheries are attempting to optimize their economics (i.e., reduce costs and increase revenues) with individual fishing quota (IFQ) management [9]. Gear restrictions, seasonal closures, and self-imposed regulations are much more common, and are implemented by most coastal and offshore fisheries [3]. However, previous studies suggest that these management measures are insufficient. For example, several authors have pointed out that Japanese fisheries are underperforming with respect to yield, profits, and maintaining stock levels, and has seen some declines in its commercially significant stocks (e.g., Japanese sardines, walleye pollock, and chub mackerel [10–14]).

In December 2018, the government of Japan passed a bill to amend

* Corresponding author. 18 Tremont St., Suite 850, Boston, MA 02108, USA.
E-mail addresses: ktokunaga@gmri.org (K. Tokunaga), gakugaku@iwate-u.ac.jp (G. Ishimura), siwata0@kaiyodai.ac.jp (S. Iwata), keita.abe@nhh.no (K. Abe), kotsuka@edf.org (K. Otsuka), kkleisner@edf.org (K. Kleisner), rfujita@edf.org (R. Fujita).
1 Present address: Gulf of Maine Research Institute, 350 Commercial Street, Portland, Maine 04101, USA.
2 Fisheries production sector employment statistics available from http://www.maff.go.jp/j/tokei/sihyo/data/18.html. Fisheries production value available from http://www.maff.go.jp/j/tokei/kouhyou/gyogyou_seigaku/.

https://doi.org/10.1016/j.marpol.2019.103646
Received 10 December 2018; Received in revised form 30 July 2019; Accepted 30 July 2019
Available online 17 August 2019
0308-597X/

the Fisheries Act, which aims to revitalize Japanese fisheries by implementing more rigorous stock assessments and management approaches based on achieving maximum sustainable yield (MSY) [15]. The bill aims to expand the scope of TAC-managed fisheries by setting TAC targets for 80% of the catch [15]. It also envisions that more fisheries will be managed with IFQs, beginning with those managed under licenses [15]. As these fisheries are larger in scale, management changes in these fisheries have greater impacts on overall stock status, yield, and fishery revenues than in Japan's coastal fisheries.

Globally, management that attempts to keep biomass at a level that will achieve MSY has become a widely accepted approach, endorsed by the Food and Agriculture Organization of the United Nations as the reference point that should be used to assess the sustainability of fish stocks for the Sustainable Development Goals Indicator 14.4.1.[3] Regionally, MSY has also been popular. The United States was an early adopter of the MSY-based approach, which dates to the 1976 Magnuson-Stevens Fishery Conservation and Management Act [16]. The European Union (EU) also adopted the MSY-based approach through a revision of the Common Fisheries Policy in 2013 [17]. Perhaps because of the much earlier adoption of an MSY-based approach to set TACs in the US, as well as other factors such as improved monitoring, control, surveillance, enforcement, assessment techniques, and generally high levels of adherence to science-based limits on catch, US fisheries stocks have recovered in many instances. While the EU has also seen some improvement in fishery outcomes, not enough time has passed since the implementation of the MSY approach to evaluate its efficacy [18–20].

In general, TACs are effective tools, if set according to robust scientific advice and enforced, that can help to maintain the biomass levels of target stocks, and can help to stabilize yields and increase fishery profits, which are important for revitalizing fisheries [21,22]. However, it is important to realize that implementing TACs without further regulations (e.g., IFQs) in an effort to achieve MSY may fail to prevent a race to fish, which can result in overcapitalization, low levels of profitability, and low compliance with TACs [23–25]. Additionally, several studies suggest that fisheries management systems that allocate secure rights to access and harvest fishery resources (often referred to as rights-based management, or RBM, systems) such as IFQs and individual transferable quotas (ITQs) improve the profitability of fisheries and promote resource conservation compared with open access fisheries that lack effective common pool resource governance [12,26–28]. Therefore, Japan's proposed plan to impose more TACs and simultaneously increase the prevalence of IFQ systems may help improve social and economic benefits [29].[4] No studies have thus far evaluated this thesis. The present study intends to bridge this gap by comparing the projected effects of maintaining current fishing mortality rates (business-*as*-usual) versus adjusting fishing mortality rates to achieve MSY, or adjusting fishing mortality rates to optimize fishery economics with rights based management (RBM) systems such as IFQs in Japanese fisheries.

The major challenge in projecting these outcomes stems from the limited scope of stock assessments of Japanese fisheries resources. While sophisticated stock assessments (i.e., models that go beyond surplus production models) exist for major stocks such as sardines (*Sardinops melanostictus*), mackerel (*Scomber japonicus*), pollock (*Theragra chalcogramma*), and yellowtail (*Seriola quinqueradiata*) [30], there is still a dearth of estimated biological reference points from stock assessments for the majority of fisheries in Japan. Overall, 84 stocks of 131 Japanese stocks are assessed using some type of assessment model. However, of these only 37 stocks have estimates of their stock status (B/B_{MSY} and F/F_{MSY}) as estimated in a policy simulation study by Ichinokawa et al. [1]. To evaluate and compare the outcomes of different management strategies for Japanese fisheries, therefore, it is first necessary to increase the number of fish stocks with status estimates relative to MSY reference points. In addition, previous stock assessment efforts have not evaluated the economic effects of different fishery management approaches for Japanese fisheries. Therefore, this study is the first to evaluate the potential effects of implementing different management policies, including an MSY-based approach, on the biomass, yield, and profit of fisheries resources in Japan.

Building on a work by Costello et al. (2016) [26] that conducted global analysis of biological and economic gains attained from alternative fisheries management scenarios, this study evaluates the potential effects of implementing different management policies, including the MSY-based approach, on the biomass, yield, and profit of fisheries resources in Japan. A part of the global analysis by Costello et al. (2016) [26] examined Japanese fisheries. However, they used RAM Legacy Assessment Database and FAO's global capture production database. Only 18 Japanese stocks are covered by the RAM Legacy Assessment Database. For the rest of the stocks using the FAO database, stocks are crudely defined based on species and production area by FAO major fishing area. Though this may be sufficient for global-scale analyses, there is a merit in conducting a country-level analysis by using more detailed data covering a wider range of stocks.

In this study, we constructed a new dataset containing landings and ex-vessel price for the 95 commercially exploited stocks from Japan's waters. With this dataset, we first calculated MSY-based reference points for these stocks that lack stock assessments by using a data-limited method that requires only catch data. Fishing effort data are not available for many stocks in Japan, precluding an analysis of the catch-per-unit effort (CPUE), which is often used as a proxy for abundance, or the use of other more complex, data-rich stock assessment methods. However, detailed landing time-series data for most commercially exploited species in Japan are available at the prefectural level. This study thus applies a catch-MSY model [26,31] to these data to estimate the MSY reference points. Then, simulations are used to examine the effects of 2 alternative fishery policies on biomass, yield, and profits: (1) a scenario in which fishing mortality to a level that achieves MSY and (2) a scenario in which the fishing rate is economically optimized as result of the implementation of a rights-based approach. Overall, this study contributes both a more comprehensive accounting of the current status of Japan's fisheries than was previously available, and a projection of the trajectory of key fisheries metrics under alternative management strategies, which may help support the further development and implementation of the amended Fisheries Act.

The remainder of the paper is organized as follows. Section 2 describes the data used, our methodology for estimating the MSY reference points, and the bioeconomic simulation model used to project the effects of different policy scenarios. Section 3 presents stock biomass levels relative to the estimated MSY biomass level and simulation results using the most recent stock status estimates (2015). In Section 4 we discuss the implications of these findings and in Section 5 we explore the prospects of fisheries policy reform given the insights gained from the bioeconomic simulation.

2. Methodology

Publicly available data from the Fisheries Agency of Japan were used to construct a time series of landing data for each stock. Specifically, landing data are available from the Survey on Marine Fishery Production, compiled and published by the Fisheries Agency (www.maff.go.jp/j/tokei/kouhyou/kaimen_gyosei). The dataset covers

[3] This indicator measures the sustainability of the world's marine capture fisheries by their abundance. A fish stock of which abundance is at or greater than the level, that can produce the maximum sustainable yield (MSY) is classified as biologically sustainable. In contrast, when abundance falls below the MSY level, the stock is considered biologically unsustainable. The indicator will measure progress towards SDG Target 14.4. See http://www.fao.org/sustainable-development-goals/indicators/1441/en/.

[4] The plan also mentions government-facilitated IQ transfers [15]. Although the ITQ system has not yet been implemented in Japan, it has been discussed both by policymakers and by academics [12,44,45].

the time period from 1964 to 2015, and records landed volume for 86 species categories, excluding seaweed species and marine mammals, by all 39 coastal prefectures (see Appendix A1 for descriptive statistics table). To construct a stock-level dataset, we first examined the habitat range for the coastal stocks assessed by the Japan Fisheries Research and Education Agency (http://abchan.fra.go.jp/index1.html) to determine which prefectures' catches come from which stock. When habitat ranges were unclear from the information in the stock assessment reports, peer-reviewed studies were consulted (see Appendix A2). Each highly migratory international fish stock was considered to be a single stock since they are widely distributed. Owing to the lack of sufficient information, unassessed coastal stocks were also considered to be a single stock. In total, 95 fish stocks were defined and analyzed in this study.

The production value of the same species categories by the 39 prefectures are also available from the Fisheries Agency of Japan (www.maff.go.jp/j/tokei/kouhyou/gyogyou_seigaku), but the time series of this dataset is shorter, covering the period from 2003 to 2015. The dataset was reorganized to match the stock-based production dataset following the same process to match the stock categories determined for the production data. The ex-vessel prices for each stock were estimated as the quotient of production value over volume. All prices were converted from Japanese yen into US dollars at the rate of 1 yen = 0.0090 USD. Because of the short time series of the dataset and no significant inflation over this period, prices were retained at nominal values.

2.1. Estimating current status

Two alternative policy scenarios were examined in this study: (1) a fishing mortality that achieves MSY (termed FMSY herein) and (2) an economically optimal policy that seeks to maximize profits given the biomass level in each year (EOpt)[5] [26]. These alternatives were also compared against business-*as*-usual (BAU), which maintains the current fishing mortality rate into the future. This study employed a variation of the "Catch-MSY" method [31] to estimate the status (B/B_{MSY} and F/F_{MSY}) of each stock. These values were used to initialize the bioeconomic policy simulation. Briefly, the Catch-MSY method is based on finding "viable" pairs of the intrinsic growth rate (*r*) and carrying capacity (*K*) for a given stock from the landing data using a Schaefer production model. Viable pairs of these parameters are defined as those that maintain the population size without allowing it to collapse given the observed catches or that exceed the carrying capacity according to estimates of the initial and final levels of stock depletion determined from the catch time series [31]. The average annual biomass level and stock status were then calculated from the *r* and *k* pairs with a Schaefer production model [31,32]. This study used the methods of Costello et al. [16] and the estimates from the Catch-MSY model to initialize a basic logistic surplus production model (i.e., the Pella–Tomlinson model [26,33]) to estimate the future biomass (B_{t+1}):

$$B_{t+1} = B_t + \frac{\phi+1}{\phi} g B_t \left(1 - \left(\frac{B_t}{K}\right)^{\phi}\right) - H_t, \tag{1}$$

where B_t represents the biomass at time *t*, H_t represents the harvest or catch at time *t*, and $\frac{\phi+1}{\phi}g$ represents the intrinsic growth rate. The parameter *phi* (ϕ) is a scaling parameter that satisfies the condition such that

$$\frac{1}{(\phi+1)^{1/\phi}} = \frac{B_{MSY}}{K}. \tag{2}$$

Phi is defined here to be 0.188, following Costello et al. [16]. The sustainable yield for the fishery is given by

$$H_t = \frac{\phi+1}{\phi} g B_t \left(1 - \left(\frac{B_t}{K}\right)^{\phi}\right). \tag{3}$$

Therefore, the MSY at the equilibrium is achieved when the fishery catch rate is $F_{MSY} = g$, and the MSY and associated biomass (B_{MSY}) are defined as

$$MSY = \frac{gK}{(\phi+1)^{1/\phi}}, \quad B_{MSY} = \frac{K}{(\phi+1)^{1/\phi}}. \tag{4}$$

Only a time series of catch data and basic life history information are needed to run the Catch-MSY model that provides the inputs for the Pella–Tomlinson model. While cohort models (e.g., virtual population dynamic models) are commonly used to assess the biomass stock status to set a TAC, they require detailed data (e.g., a stock–recruitment relationship, natural mortality, and age/length compositions of catches). In particular, the estimation of the stock–recruitment relationship, which demands the collection of long-term and intensive data, is a critical component for using such models.

The Catch-MSY method allows us to estimate MSY reference points for more stocks, which in turn allows us to conduct a wider-scale regional analysis than was previously possible. When only a limited number of exploited stocks are assessed, it is difficult to evaluate the overall health of the fisheries in a country. As noted above, in Japan, 84 stocks of 131 stocks are assessed. However, only 37 stocks have MSY-based estimates of stock status (B/B_{MSY} and F/F_{MSY}) [1]. The remaining 47 stocks are assessed qualitatively using catches and other available data. Given the long time series of the catch data available for most species exploited in Japan, coupling the Catch-MSY model to the Pella–Tomlinson surplus production model provides a pragmatic way to assess the current and projected stock status for most Japanese fisheries.

While the relatively low level of data required for this method are a clear advantage, there are some limitations. First, the Catch-MSY method is founded on the idea that the catch is a good proxy for stock dynamics (i.e., it assumes that variations in landings reflect variations in stock abundance). Thus, it may be unsuitable if catch trends vary because of external factors such as environmental changes, weather, fisheries regulations, and other conditions that cause catch patterns to deviate from the underlying biomass dynamics. Second, the method requires long time series of catch data and assumes that the "typical" phases of the fishery are captured (e.g., development, peak catch, overfishing, rebuilding) to estimate initial and final depletion levels. If the available catch data do not cover the entire history of the fishery, the estimated parameters may differ from the actual values. Third, the method assumes stationary production (i.e., that the intrinsic growth rate and carrying capacity are stable). Sensitivity analyses were conducted in this study to examine the robustness of the estimates given these assumptions by changing the input values of (B_{MSY}/K) to check how this parameter value affects the Catch-MSY estimates. Again, it is important to note that stock estimates based on more sophisticated models exist for certain stocks (E.g Ref. [1]); however, we need a common approach that can be applied to a wider range of stocks to ensure the biomass reference points are estimated on equal footing. The Catch-MSY method provides this platform, and thus is suitable for our analysis. However, given the importance of the stock recruitment relationship and cohort strength in determining biomass and potential yield for many species (which are not accounted for in the catch-MSY method), the results should be used with caution for strategic purposes (e.g., evaluating potential trade-offs between policy options, as we do here) and not for fisheries management or business planning.

2.2. Policy simulation

Bioeconomic model simulations were conducted to analyze and

[5] EOpt is an economically optimal management scenario, parameterize to reflect an RBM approach, in which fishing costs are reduced and prices increased based on the empirical performance of ITQ fisheries.

Table 1
Input parameter values.

Parameter	Description	Input value	Notes
ϕ	Scaling parameter	0.188 (default) 0.06 (sensitivity analysis lower bound) 0.3 (sensitivity analysis upper bound)	Default value from Costello et al. [26]
δ	Discount rate	0.02	Expert opinion
β	Scalar cost parameter that determines how non-linear the costs are.	1.3	Based on Costello et al. [26]
Ratio domestic catch	Proportion of catch by domestic fleet	0.6	Based on Japanese expert opinion
γ_P	Price scalar that reflects economic incentives (price increases)—can be set specifically for each fleet, but no differentiation made in this analysis	1.31	Based on expert opinion from Costello et al. [26]. 31% price increase when reforms applied.
γ_C	Cost scalar that reflects economic incentives (cost decreases)—can be set specifically for each fleet, but no differentiation made in this analysis	0.77	Based on expert opinion from Costello et al. [26]. 23% cost decrease when reforms applied.

compare the two policy alternatives: FMSY and EOpt. They were also compared against the BAU scenario. Details of the full bioeconomic simulation method are described in Costello et al. [26]. In brief, the economic model calculates the profits given the biological parameters estimated from the biological model (equation (1)) and price data. A fishery maximizes the net present value of profit by controlling the fishing mortality rate in each time step. By denoting $b_t \equiv B_t/B_{MSY}$ and $f_t \equiv \frac{F_t}{F_{MSY}}$, the objective function can be expressed as

$$Maximize_{f_1,f_2,\ldots} \sum_{t=1}^{\infty} \frac{\pi(b_t, f_t)}{(1+\delta)^t}, \tag{5}$$

where the profit function is expressed as

$$\pi_t = pH_t - cF_t^{\beta} \tag{6}$$

In equation (6), p represents price, c represents the cost scalar, F_t represents the fishing mortality rate at time t, and β is a positive scalar that governs the non-linearity of total costs. Our model does not explicitly examine changes in fishing behaviors or investments under different policy alternatives. Instead, our model assumes that ex-vessel prices (p) increase by 31%, and costs (c) are assumed to decrease by 23% if a fishery adopts a rights-based management approach, based on the mean changes in prices and costs observed in RBM fisheries [26].

Table 1 shows the key input parameter values used in the simulation.[6] The first three parameters are as described above. Because our analysis includes migratory stocks caught by both domestic and foreign vessels, while the landings data only capture catches by domestic vessels, the ratio of domestic catch to total catch is set to 0.6 based on experts' opinion. The parameters γ_P and γ_C are scalars of the price and cost, respectively, and are used in the EOpt scenario.

3. Results

The $B_{current}/B_{MSY}$ and $F_{current}/F_{MSY}$ values estimated with the Catch-MSY method are displayed in a Kobe plot (Fig. 1). To examine the effect of the deviation from the default input value of *phi* (ϕ) = 0.188, we also tested the values of 0.06 and 0.3[7] (Fig. 1). Varying the values of ϕ did not change the average status on the Kobe plot, suggesting that the use of the default parameter did not affect the results greatly. In general, larger estimates of B_{MSY} are more sensitive to changes in ϕ. This finding implies that the variance of the estimated B_{MSY} parameters may be larger for stocks with larger estimated B_{MSY}.

Changing the value of ϕ provided one check of the model's robustness. Within the range of the ϕ values examined, all 95 stocks converged on reasonable point estimates for parameters with ϕ equal to either 0.188 or 0.3, and 94 stocks converged when *phi* was set equal to 0.06. Within the range of the ϕ values examined, the values reported in Fig. 2 demonstrate the upper and lower bounds of B_{MSY}. Overall, the biological parameters estimated by the Catch-MSY method are robust to the assumption of ϕ equal to 0.188. We therefore report results based on this value of ϕ.

In the BAU scenario, the biomass trajectory of each stock was simulated starting with the B/B_{MSY} estimates from the Catch-MSY model for 2015 to 2065 by assuming that fishing mortality levels would stay at the 2015 level (Fig. 3). Forty-nine of the 95 stocks examined (52%) exhibit decreasing future biomass trends, depicted in blue. Forty six of the stocks (i.e., 48% of those examined) show increasing biomass trends. These stocks tend to be those with $F_{current}/F_{MSY}$ less than one in 2015 (i.e., low levels of current fishing mortality) meaning that maintaining low fishing mortality levels allowed biomass to continue to grow, as one would be expected.

The status in the current year (2015) was compared with the status in year 50 (i.e., 2065) of the simulation under each of the three examined policies (Fig. 4). The Kobe plot showing the current stock status indicates that 51% of stocks are experiencing overfishing with $F_{current}/F_{MSY}$ being greater than 1 and 79% are overfished with $B_{current}/B_{MSY}$ being less than 1 (Fig. 4, upper left panel). Under the BAU scenario, these high levels of fishing mortality continue for the stocks experiencing overfishing, resulting in lower levels of biomass for these stocks in the future as exploitation pressure is maintained (Figs. 3 and 4, upper right panel). For stocks that have a status closer to F/F_{MSY} = 1 and B/B_{MSY} = 1, the biomass remains steady or drops slightly. Under the FMSY scenario, fishing pressure is reduced for many stocks; yet, many are still below the B_{MSY} level at the end of the simulation, presumably because F_{MSY} is not sufficiently low to allow overexploited stocks to recover to B_{MSY}. The EOpt scenario results in the recovery of many overexploited stocks (B/B_{MSY} > 1), which tends to increase profitability by increasing catch rates and reducing fishing costs [34], while keeping fishing mortality sufficiently high to produce fairly high yields.

Fig. 5 shows the average biomass trajectories for all stocks over the 50-year simulation period after 2015 for each policy scenario. Under all scenarios, the average biomass increases. While the EOpt scenario leads to the highest biomass levels, the BAU and FMSY scenarios exhibit similar increasing biomass trajectories, but resulting in lower biomass levels than under EOpt. As described earlier, more than half of stocks appear to be experiencing overfishing (Fig. 4, upper left panel). However, only 19% have $F_{current}/F_{MSY}$ greater than 2. Furthermore, the biomass for these 19% of stocks accounts for 4% of the total biomass amount. This probably explains in part the similarity between the BAU and FMSY biomass trajectories. In 50 years, the biomass level under the EOpt scenario recovers to the same level as estimated for the mid-1970s and the biomass is 30% greater than that in the BAU scenario.

Fig. 6 shows the average catch trajectories for all stocks over the 50-year simulation period after 2015 for each policy scenario. The BAU scenario results in low catches in the long run. The FMSY scenario requires lower catches in the short term to realize higher catches in the

[6] See the supplementary information of Costello et al. [26] for the details of the simulation approach and other parameter values used in the simulation.

[7] These values are plus or minus 10% of the default input value of ϕ = 0.188.

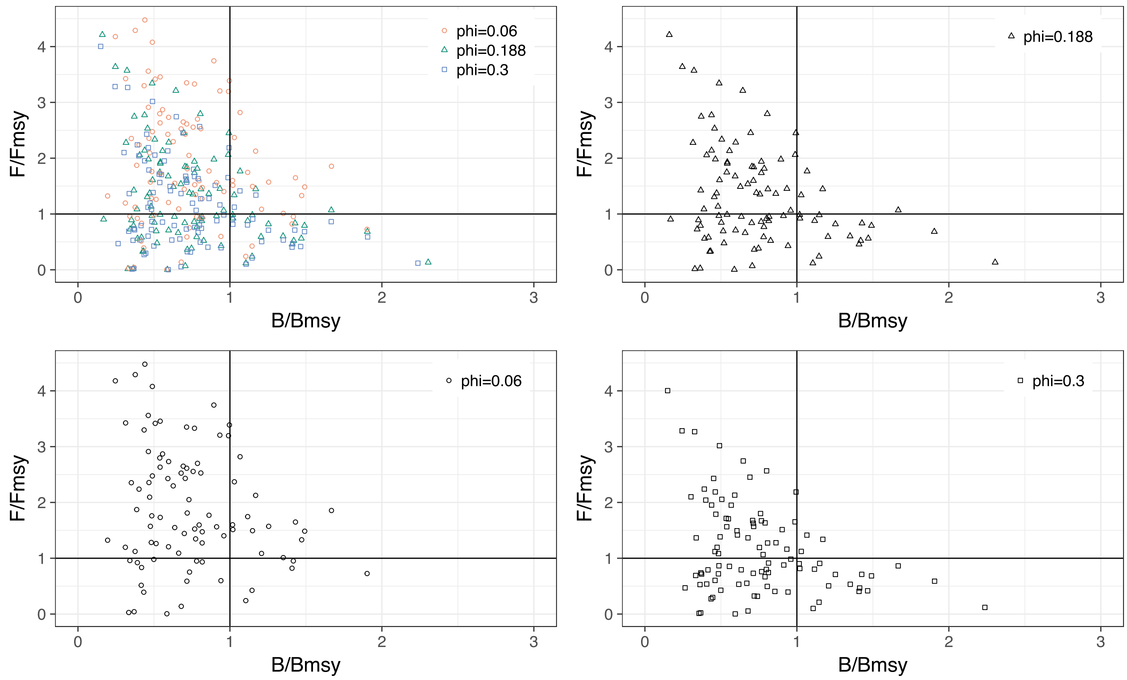

Fig. 1. Kobe plots under different assumptions of phi (ϕ) values using current status estimates.

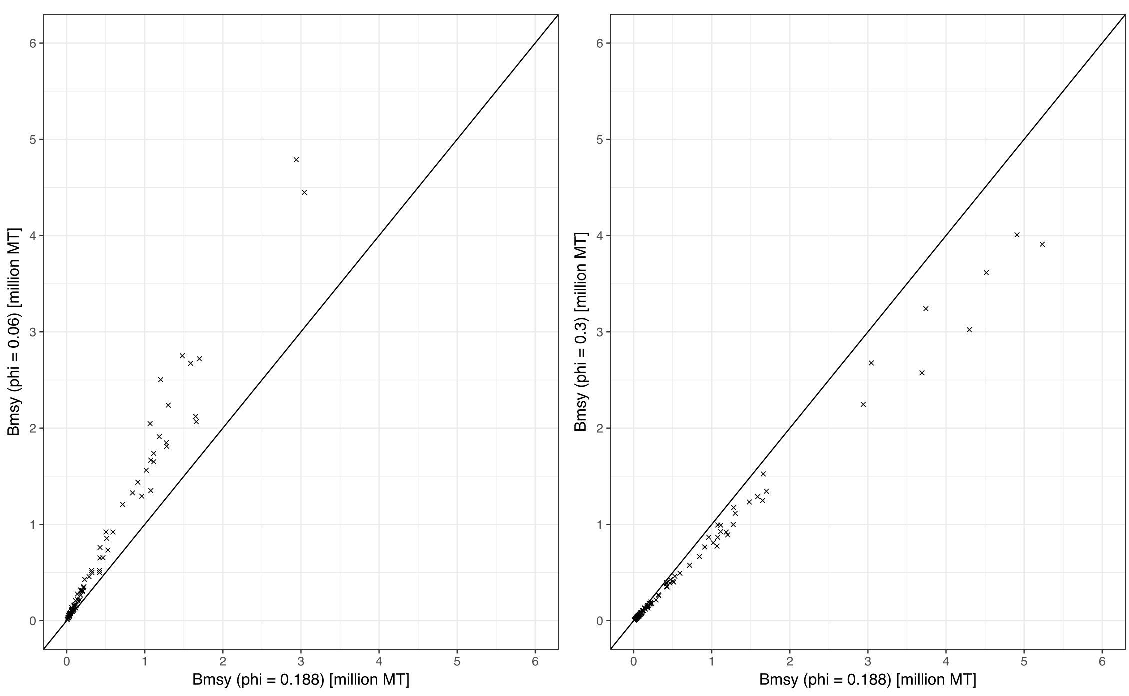

Fig. 2. Sensitivity to the assumptions of the phi (ϕ) values.

long term. Under the EOpt scenario, the catch needs to be reduced far more in the near-term than under either of the other two scenarios to allow stocks to recover, but this policy ultimately generates the highest yields and profits because more stocks are maintained at biomass levels capable of producing MSY.

Fig. 7 shows the annual profit trajectory over the 50-year simulation period. The trajectory, again, is for the aggregate of all the stocks examined in this study. Annual profit under the EOpt scenario drops sharply in the short run but surpasses profits under the FMSY scenario after 15 years. The figure shows that the BAU scenario results in the lowest profit throughout the simulation period[8]. In the long run, the EOpt policy allows a fishery to earn over 3.5 times as much annual profit as that generated under the BAU scenario. This translates into a USD 5.5 billion annual profit difference by the end of the simulation period.

[8] The difference in profits between EOpt and BAU in the initial period is driven by our assumption that rights-based management increases the ex-vessel price by 31% and reduces the costs associated with fishing by 23%, based on the global study [26].

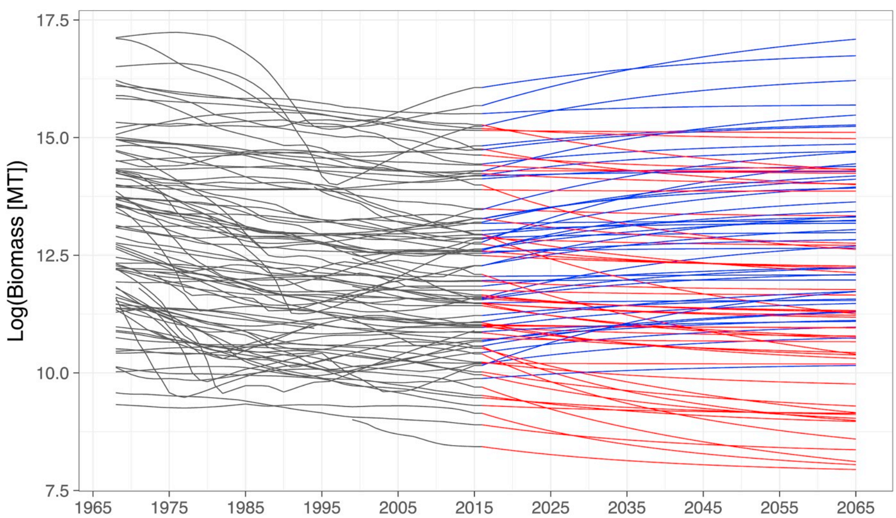

Fig. 3. Biomass trajectories under business-*as*-usual scenario, showing natural log of estimated biomass levels. Historical estimates are shown in gray. Stock trajectories shown as blue indicate stocks with increasing biomass trends. Stock trajectories shown as red indicate stocks with decreasing biomass trends. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

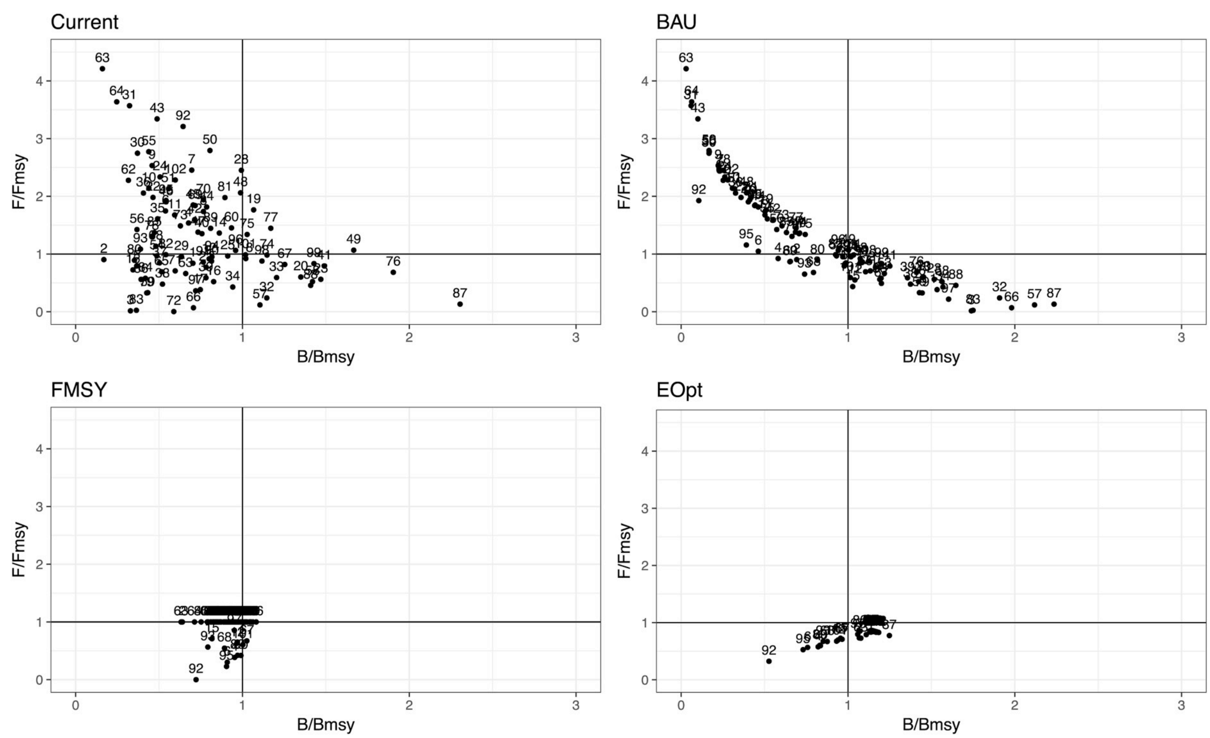

Fig. 4. Kobe plot under alternative policy scenarios, comparing current status (upper left panel) with the status obtained under each of the three policy scenarios in the 50th year of the simulation. Each point corresponds to an individual stock.

Finally, Fig. 8 shows the differences in the total available biomass, total catch, and total net present values in the 50-year simulation periods. The EOpt policy results in the highest available biomass and yields the highest net present value, while the FMSY policy yields the largest cumulative catch. This combined with the catch trajectories shown in Figs. 5–7 indicate a tradeoff: the EOpt policy requires larger reductions in catch in the near-term in order to ultimately increase biomass levels and profits compared with the FMSY policy.

4. Discussion of simulation results

We estimated the impacts and tradeoffs of two proposed MSY-based fishery policy reforms, and their relative performances to a ‘business as usual’ policy on the biomass, catch, and profits for Japanese fish stocks: maintaining F_{MSY}, and optimizing fishery economics with an RBM policy. Using a data-limited method to assess 95 Japanese stocks, we were able to obtain a more complete, albeit uncertain, picture of the status of Japan's fisheries. Notably, just over half of the stocks we assessed appear to be experiencing overfishing, and 79% of the stocks appear to be overfished.

The total biomass of all of the stocks we examined could increase in the future if our estimate of fishing mortality is accurate. This is because fishing mortalities for 47 stocks, which represent the majority of the total biomass, are estimated to be less than F_{MSY} currently. However, individual stock biomass would likely remain below the B_{MSY} level for the majority of stocks if Japan elects the BAU scenario, resulting in less yield and profit than these fisheries are capable of producing. There would probably be a significant improvement in catch and profits if Japan were to maintain fishing mortality at F_{MSY} levels. However, biomass might rise only marginally under this policy. EOpt policy leads to the highest biomass, catch, and profits in the long-run; however, catches would have to be reduced significantly over the short term to

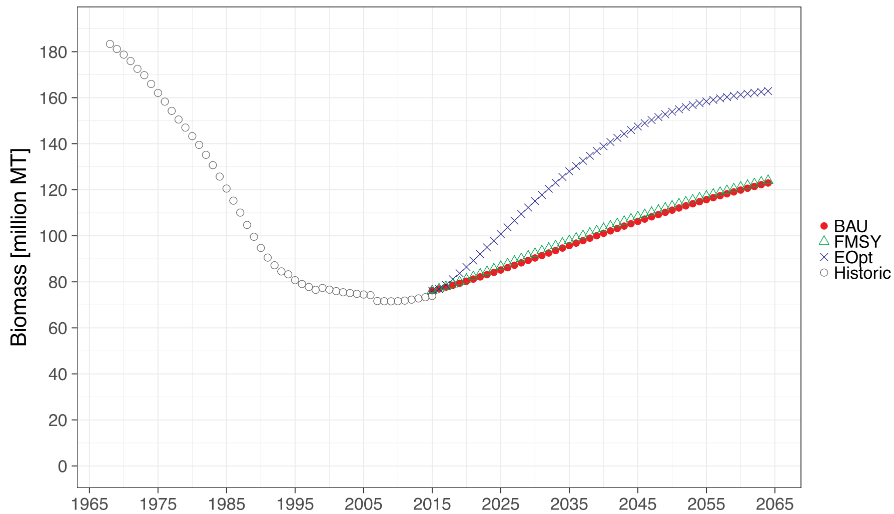

Fig. 5. Biomass trajectory under the three policy scenarios.

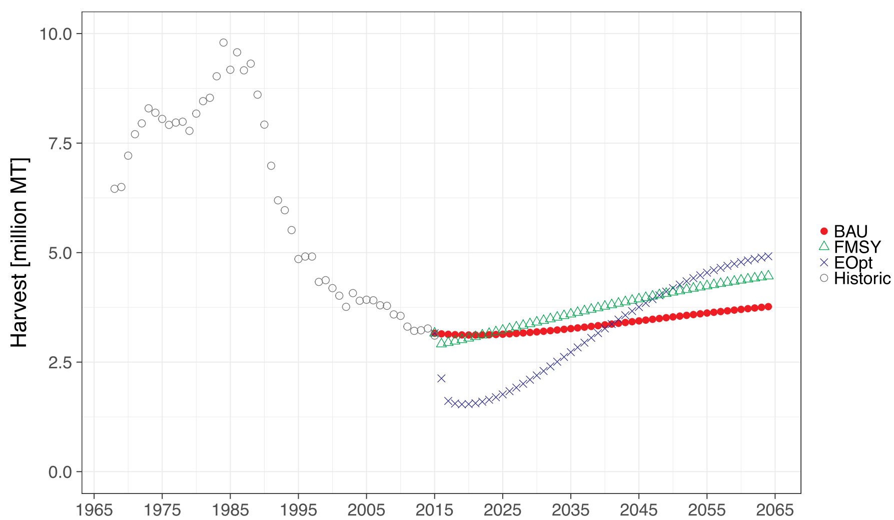

Fig. 6. Catch trajectories under the three policy scenarios.

realize these benefits. These results indicate that limiting fishing mortality to F_{MSY} without other measures that optimize fishery economics (such as RBM), while a positive step, could be insufficient to maximize biomass, yield, and profits. Coupling F_{MSY} management with rebuilding plans that reduce catches over the short term to rebuild stock biomass and with management systems that optimize the economics of Japan's fisheries such as RBM would be expected to result in the highest biomass, catch, and profit levels of the scenarios considered here. However, this economic optimization policy would require the largest reductions in allowable catches in the short term.

The Catch-MSY estimates of the MSY reference points (B/B_{MSY} and F/F_{MSY}) show that the majority of stocks could be overfished, meaning that they are unlikely to recover unless catches are reduced. A similar observation was made by Ichinokawa et al. [1] for the 37 stocks they assessed, namely those most closely monitored by the Fishery Agency and the Fisheries Research and Education Agency of Japan [1] [9]. These results indicate that stock overexploitation has occurred irrespective of whether the stock status is monitored and assessed regularly, and suggests that not only are more stock assessments necessary (as the majority of Japanese stocks lack stock assessments and MSY reference points), but alternative or additional management measures will also be needed.

From the policy simulation conducted in this study, 48% of stocks display increases in future biomass—even under the BAU scenario – because their current fishing mortality levels appear to be below F_{MSY}. However, these increases in biomass would be insufficient to rebuild stock biomass to levels capable of supporting MSY under the BAU scenario, and the majority of the stocks would likely continue to experience overfishing.

The amended Fishery Act of Japan embraces MSY-based fisheries management by setting TAC targets for 80% of the total catch [15]. However, our results suggest that simply setting the TAC targets in this way would not achieve as much stock recovery, in terms of biomass, catch, or profit as could the EOpt policy, which is modeled to reflect gains that could be achieved under a rights-based fisheries management approach (i.e., lower costs and higher prices).

The bioeconomic policy simulation suggests that biomass, catch, and profits increase in the long-run if Japan were to adopt a policy that

[9] Page A-16 of Ichinokawa et al.'s [1] online appendix shows the Kobe plots.

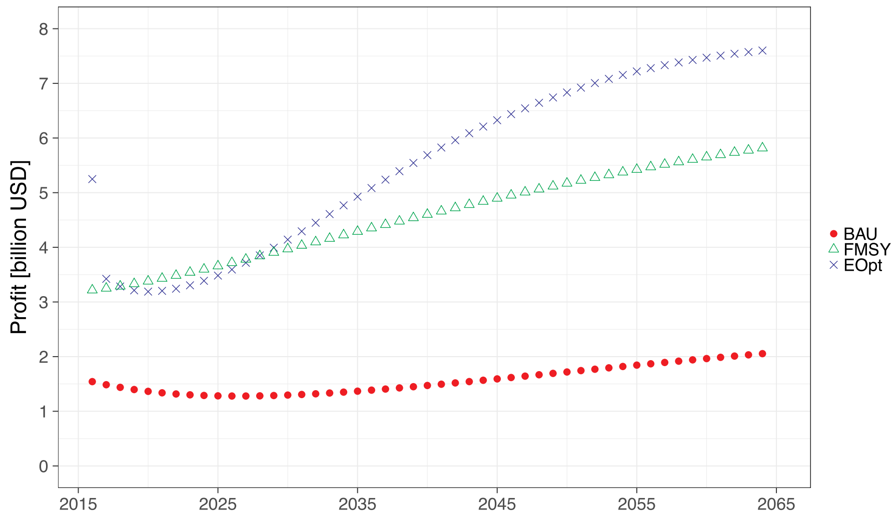

Fig. 7. Profit trajectory under the three policy scenarios.

optimized for profits and biomass. However, the results illustrate a sharp reduction in catches over the first few years, which would result in lower yields and profits in the short term than under the FMSY scenario. It would take roughly 35 years to attain the same catches and 15 years to attain the same profits as in the FMSY scenario. Under the BAU and FMSY policies, catches would be kept at roughly the current level. However, these policies, especially the BAU policy, would require fisheries to sacrifice potential profits. Nonetheless, because Japan has a large number of aging fishermen (over 38% of fishers are 65 years or older[10]), it may be possible to reduce the social and economic impacts of the reduced allowable catches necessary to rebuild stocks as fishermen retire and leave the fishery. Indeed, this reduction in the number of fishermen may present an opportunity to implement a rights-based system with individual quotas, which typically entails a reduction in overall effort in the fishery [35,36], with less social and economic dislocation than would be the case if attrition rates were low. As fishery resources rebuild sufficiently to generate high yields and profits, higher profitability may attract more entrants to the fishery resulting in overcapitalization and a reduction of individual benefits from the fishery. This may be another incentive to move towards a rights-based system which can allow fishing capacity to adjust to available catch [37]. Otherwise, it may be necessary to create opportunities for alternative livelihoods (e.g., aquaculture, tourism, etc.) or provide subsidies to mitigate the impacts of the reductions in catch necessary to maximize long term yields, profits, and biomass.

These results suggest that profits would be higher under the EOpt scenario than the BAU scenario, as higher prices and lower costs are projected to occur based on the performance of RBM systems. Because no studies have thus far examined the possible impacts of implementing RBM in Japanese fisheries, these assumptions and the parameter values were taken from a global study of RBM fisheries and expert opinion [26]. To improve the simulation, future studies should investigate the potential price and cost changes that Japanese fisheries could attain from implementing RBM. For instance, an examination of how implementing IQ programs has affected the prices and costs of Southern bluefin, Atlantic bluefin, and red snow crab fisheries could inform future analyses.

The projections of catch, biomass, and profit under alternative policy scenarios elucidate the advantages, disadvantages, and necessary tradeoffs inherent in each for all the stocks examined in aggregate. To present and discuss the results at the species or stock level for setting TAC levels, substantial improvements would be needed. For instance, the Catch-MSY method used in this study assumes a uniform growth function and parameter values for all stocks. While this approach is appropriate for the comparison of the gross effects of the different policy scenarios, formal assessments of individual stocks are needed for accurate single-stock projections. Furthermore, considering the potential benefits, the costs of formal stock assessments would most likely be justified in fisheries that have high yields and revenues. Yet, for many fisheries and stocks, cost could be a barrier to formal assessment. A host of methods, including Catch-MSY methods and production models (with stock-specific parameters), could be applied to assess stock status and project the performance of individual fisheries with respect to future biomass, yield, and profit under different management scenarios [38], although they have still not been tested thoroughly for tactical management [39] Multi-indicator adaptive management approaches that require only a few data streams may be appropriate for guiding the management of data-limited fisheries [40–42].

Japan's recently passed fisheries reform plan is aimed at expanding the scope of MSY-based management and adoption of IFQs in more fisheries. As illustrated by our simulations, the proposed reform could transform Japanese fisheries into more sustainable and profitable enterprises. Yet, as noted by other global examples [43,44], actual implementation of fisheries reform faces multiple challenges. Who would bear the cost of scientific studies? How should the quotas be allocated? How should the rules be enforced? These are the questions that still need to be answered and should be the focus of future research and deliberation.

5. Fisheries reform implementation issues

Japan's recently passed fisheries reform plan includes a large increase in the number of fisheries subjects to TAC limits with the aim of increasing yields and revitalizing Japan's fisheries sector. Implementation of the plan will likely require the use of MSY reference points and perhaps IFQ programs. As illustrated by our simulations, the implementation of TACs aimed at maximizing sustainable yield and programs like Individual Fishing Quotas which can improve the economic performance of fisheries could result in higher yields, higher profits, and larger fish populations. The actual implementation of these policy reforms will face multiple challenges, based on other national policy reform experiences [43,44].

[10] Fisheries production sector employment statistics by age available from http://www.maff.go.jp/j/tokei/sihyo/data/18.html.

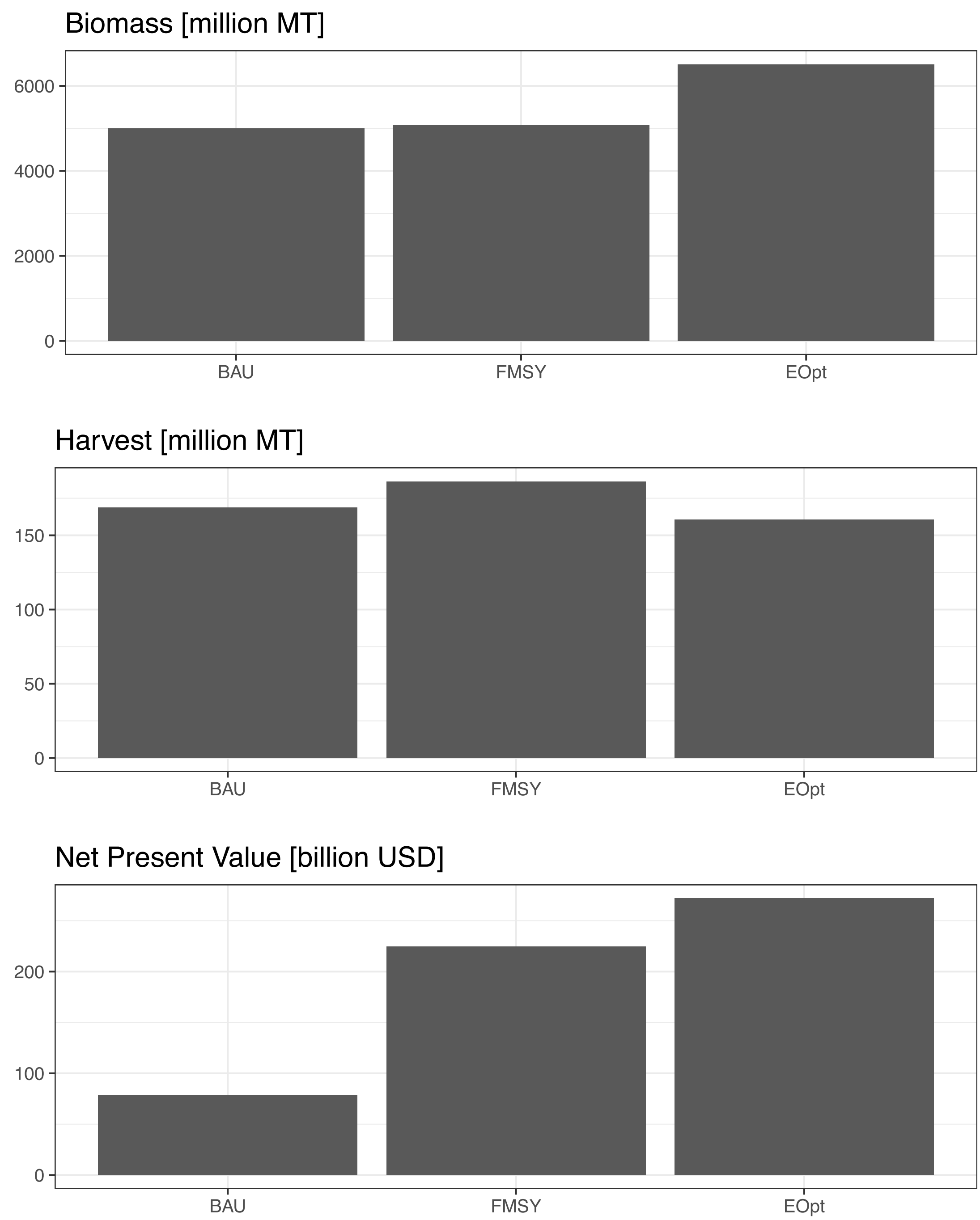

Fig. 8. Cumulative outcomes under the three policy scenarios in the 50-year simulation periods.

The effectiveness of fisheries management based on TACs relies on the accuracy and reliability of stock assessment. Currently, the stock assessment process in Japan does not include peer review. Both the quality and reliability of the stock assessments can be improved by the introduction of peer-review steps in the process. In addition to the need for more data discussed earlier, there is also room for improvement of data collection and data management systems in order to improve the stock assessments. Because almost all landings go through landing markets, in theory, landings information is available for almost all commercial operations. However, landings information is usually managed by local Fisheries Cooperative Associations, and thus recording formats, species categorization, and measurement systems are not standardized. Standardizing the process of data collection and management, as well as establishing data-sharing rules for scientific assessment would reduce the administrative burden associated with stock assessments. Improved data management procedures will also benefit the peer-review process. Currently, access to data used in stock assessments is restricted to the researchers who are directly involved with the government's stock assessment process. The establishment of a data-disclosure procedure that supports the scientific review process is needed.

Allocating shares of TACs and defining eligibility requirements, transfer restrictions, and other rules related to quota management aimed at optimizing the economics of fisheries is often contentious and time-consuming [46]. However, taking the time to make this process highly participatory can increase the degree of procedural justice and fairness [35], reducing conflict and increasing support for the allocation and programs such as IFQs based on it over time.

Implementing catch monitoring programs, accountability measures (e.g., penalties), and measures to assure compliance (e.g., enforcement, incentives, norms, etc.) required for effective fisheries management will also be challenging. There is considerable guidance available on how to implement these kinds of measures (e.g. Refs. [22,47]), including guidance on how to use cameras and other technologies to reduce costs and increase effectiveness [48, 49].

MSY-based management using TACs and IFQs will cost more to implement than the current mix of input controls that currently dominate Japanese fisheries management. This is because monitoring, enforcement, and scientific research programs will need to be enhanced. One way to finance MSY-based management is to shift government financial transfers that facilitate overfishing (e.g., subsidies for fishing vessel construction or fuel) to ones aligned with rebuilding fishery resources (e.g., vessel buybacks, research, monitoring, and enforcement). Studies suggest that Japan provides considerable funding for the enhancement of fishing capacity, such as a tax exemption for the fishing vessel fuel (e.g. Ref. [50]). Fisheries subsidies have become a topic of the global discussion. For instance, there has been a series of negotiations at the World Trade Organization to prohibit fishing subsidies that could lead to overcapacity and overfishing [51]. The literature on fisheries subsidies suggests that government subsidies for fishing capacity-enhancement accelerate the depletion of fishery resources, while government-financed fishery management and research program developments promote sustainable use of fishery resources [51–53]. Furthermore, Yagi et al. (2009) [54] reported a positive relationship between a subsidy that supports scientific research and fisher's individual earnings. This study suggests that altering government subsidies to support management and research on enhancing biomass would improve fishery outcomes relative to the effects of the existing subsidies. Japanese subsidies that support fishing communities and local fisheries management organizations could also enhance local co-management [55,56]. Thus, there appear to be many advantages related to reallocating government subsidies to support MSY-based management.

6. Conclusion

Model projections suggest that Japanese fisheries could generate an additional USD 5.5 billion in annual profits if they are managed under the EOpt policy. Under this policy, allowable catches are reduced in the short term to allow stocks to rebuild to levels capable of producing high yields in the long run and ultimately produce greater profits. The projections presented herein also suggest that this policy could lead to a 30% increase in biomass levels. For some species, biomass levels would increase even if current fishing mortality rates were maintained (i.e., a mix of relatively high and low levels of fishing mortality relative to F_{MSY}). Nonetheless, these results suggest that this would hinder opportunities to increase the profitability of Japan's fisheries.

All fishery policies have advantages and disadvantages and all entail tradeoffs. Continuing the status quo would require no reductions in the allowable catch, but catches could decrease over time as stocks continue to be overfished and become depleted. Managing fishing mortality such that it is maintained at F_{MSY} levels would entail greater reductions in allowable catches for those fisheries being overfished but would produce greater catches and profits than the status quo. Adopting an economic optimization policy (e.g., RBM) would entail even larger short-term reductions in allowable catches, but these reductions would allow more fish stocks to rebuild their biomass levels, resulting in the highest projected yields and profits of the three policy scenarios studied here.

Acknowledgments

This work was supported by JSPS KAKENHI Grant Number JP18KT0038. We thank Momoko Ichinokawa and other participants of “The Workshop on Successful Fisheries” (Kamakura, Japan, August 2018) for their comments and suggestions. We also thank the editor and anonymous reviewers. Financial support was provided by the Kingfisher Foundation and the David and Lucile Packard Foundation.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.marpol.2019.103646.

References

[1] M. Ichinokawa, H. Okamura, H. Kurota, The status of Japanese fisheries relative to fisheries around the world, ICES J. Mar. Sci. 74 (2017) 1277–1287, https://doi.org/10.1093/icesjms/fsx002.
[2] H. Osterblom, J.B. Jouffray, C. Folke, B. Crona, M. Troell, A. Merrie, J. Rockström, Transnational corporations as “keystone actors” in marine ecosystems, PLoS One 10 (2015) e0127533, , https://doi.org/10.1371/journal.pone.0127533.
[3] M. Makino, H. Matsuda, Co-management in Japanese coastal fisheries: institutional features and transaction costs, Mar. Policy 29 (2005) 441–450, https://doi.org/10.1016/j.marpol.2004.07.005.
[4] J.P. Canchino, H. Uchida, J.E. Wilen, TURFs and ITQs: collective vs. individual decision making, Mar. Resour. Econ. 22 (2007) 391–406, https://doi.org/10.1086/mre.22.4.42629569.
[5] T. Yamamoto, Development of a community-based fishery management system in Japan, Mar. Resour. Econ. 10 (1995) 21–34, https://doi.org/10.2307/42629097.
[6] Fishery Agency of Japan, Understanding TAC (TAC seido wo shiru), n.d http://www.jfa.maff.go.jp/j/suisin/s_tac/pdf/tacpanfu201501.pdf , Accessed date: 7 December 2018.
[7] M. Makino, Fisheries Management in Japan: its Institutional Features and Case Studies, Springer Science & Business Media, Berlin, 2011.
[8] Fisheries Agency of Japan, Management of Pacific bluefin tuna, http://www.jfa.maff.go.jp/j/suisin/s_kouiki/nihonkai/attach/pdf/index-68.pdf, (2018) , Accessed date: 12 September 2018.
[9] Fisheries Agency of Japan, FY2015 trends in fisheries, FY2016 fisheries policy, white paper on fisheries: summary, http://www.jfa.maff.go.jp/j/kikaku/wpaper/attach/pdf/index-3.pdf, (2015) , Accessed date: 11 September 2018.
[10] W. Swartz, L. Schiller, U. Rashid Sumaila, Y. Ota, Searching for market-based sustainability pathways: challenges and opportunities for seafood certification programs in Japan, Mar. Policy 76 (2017) 185–191, https://doi.org/10.1016/j.marpol.2016.11.009.
[11] Y. Watanabe, H. Zenitani, R. Kimura, Population decline of the Japanese sardine Sardinops melanostictus owing to recruitment failures, Can. J. Fish. Aquat. Sci. 52 (1995) 1609–1616, https://doi.org/10.1139/f95-154.
[12] N. Yagi, M.L. Clark, L.G. Anderson, R. Arnason, R. Metzner, Applicability of Individual Transferable Quotas (ITQs) in Japanese fisheries: a comparison of rights-based fisheries management in Iceland, Japan, and United States, Mar. Policy 36 (2012) 241–245, https://doi.org/10.1016/j.marpol.2011.05.011.
[13] T. Funamoto, Causes of walleye pollock (Theragra chalcogramma) recruitment decline in the northern Sea of Japan: implications for stock management, Fish. Oceanogr. (2011), https://doi.org/10.1111/j.1365-2419.2010.00570.x.
[14] C. Watanabe, A. Yatsu, Long-term changes in maturity at age of chub mackerel (Scomber japonicus) in relation to population declines in the waters off northeastern Japan, Fish. Res. (2006), https://doi.org/10.1016/j.fishres.2006.01.001.
[15] The House of Representatives of Japan, A Bill to Parts of Fisheries Act (gyogyou hou tou no ichibu wo kaisei suru tou no houritsu an), (2018) http://www.shugiin.go.jp/internet/itdb_gian.nsf/html/gian/honbun/houan/g19709008.htm , Accessed date: 10 December 2018.
[16] B. Mesnil, The hesitant emergence of maximum sustainable yield (MSY) in fisheries policies in Europe, Mar. Policy 36 (2012) 473–480, https://doi.org/10.1016/j.marpol.2011.08.006.
[17] EU Regulation No 1380/2013 of the European Parliament and of the Council of 11 December 2013 on the Common Fisheries Policy, Amending Council Regulations (EC) No 1954/2003 and (EC) No 1224/2009 and Repealing Council Regulations (EC) No 2371/2002 and (EC, European Union), (2013).
[18] NRDC, Bringing back the fish: an evaluation of U.S. Fisheries rebuilding under the Magnuson-Stevens fishery conservation and management Act, http://www.nrdc.org/oceans/files/rebuilding-fisheries-report.pdf, (2013) , Accessed date: 7 December 2018.
[19] S. Villasante, M. Do Carme García-Negro, F. González-Laxe, G.R. Rodríguez, Overfishing and the common fisheries policy: (un)successful results from TAC regulation? Overfishing and the common fisheries policy, Fish Fish. 12 (2011) 34–50, https://doi.org/10.1111/j.1467-2979.2010.00373.x.
[20] Setting of total allowable catches in the 2013 EU common fisheries policy reform: possible impacts, Mar. Policy 91 (2018) 97–103, https://doi.org/10.1016/j.marpol.2018.01.026.
[21] M.A. Turner, Quota-induced discarding in heterogeneous fisheries, J. Environ.

Econ. Manag. (1997), https://doi.org/10.1006/jeem.1997.0985.
[22] E.R. Selig, K.M. Kleisner, O. Ahoobim, F. Arocha, A. Cruz-Trinidad, R. Fujita, M. Hara, L. Katz, P. McConney, B.D. Ratner, L.M. Saavedra-Díaz, A.M. Schwarz, D. Thiao, E. Torell, S. Troëng, S. Villasante, A typology of fisheries management tools: using experience to catalyse greater success, Fish Fish. 18 (2017) 543–570, https://doi.org/10.1111/faf.12192.
[23] F.R. Homans, J.E. Wilen, A model of regulated open access resource use, J. Environ. Econ. Manag. 32 (1997) 1–21, https://doi.org/10.1006/jeem.1996.0947.
[24] R. Deacon, D. Finnoff, Restricted capacity and rent dissipation in a regulated open access fishery, Resour. Energy Econ. 33 (2011) 366–380 https://doi.org/10.1016/j.reseneeco.2010.05.003.
[25] J.R. Beddington, D.J. Agnew, C.W. Clark, Current problems in the management of marine fisheries, Science 316 (2007) 1713–1716, https://doi.org/10.1126/science.1137362.
[26] C. Costello, D. Ovando, T. Clavelle, C.K. Strauss, R. Hilborn, M.C. Melnychuk, T.A. Branch, S.D. Gaines, C.S. Szuwalski, R.B. Cabral, D.N. Rader, A. Leland, Global fishery prospects under contrasting management regimes, Proc. Natl. Acad. Sci. 113 (2016) 5125–5129, https://doi.org/10.1073/pnas.1520420113.
[27] Property rights in fisheries, How much can individual transferable quotas accomplish? Rev. Environ. Econ. Policy 6 (2012) 217–236 http://reep.oxfordjournals.org/content/6/2/217.short.
[28] C.A. Grainger, C. Costello, The value of secure property rights: evidence from global fisheries, http://www.nber.org/papers/w17019, (2011) , Accessed date: 10 December 2018.
[29] U.R. Sumaila, W. Cheung, A. Dyck, K. Gueye, L. Huang, V. Lam, D. Pauly, T. Srinivasan, W. Swartz, R. Watson, D. Zeller, Benefits of rebuilding global marine fisheries outweigh costs, PLoS One 7 (2012) e40542, , https://doi.org/10.1371/journal.pone.0040542.
[30] Fisheries Agency and Fisheries Research and Education Agency of Japan, Marine fisheries stock assessment and evaluation for Japanese waters (fiscal year 2018/2019), http://abchan.fra.go.jp/ , Accessed date: 23 April 2019.
[31] S. Martell, R. Froese, A simple method for estimating MSY from catch and resilience, Fish Fish. 14 (2013) 504–514, https://doi.org/10.1111/j.1467-2979.2012.00485.x.
[32] M.B. Schaefer, Some aspects of the dynamics of populations important to the management of the commercial marine fishes, Bull. Inter Am. Trop. Tuna Commun. 1 (1954) 27–56.
[33] J.J. Pella, P.K. Tomlinson, A generalized stock production model, IATTC Bull. 13 (1969) 83.
[34] R.Q. Grafton, Individual transferable quotas: theory and practice, Rev. Fish Biol. Fish. 6 (1996) 5–20, https://doi.org/10.1007/BF00058517.
[35] K. Bonzon, K. Mcilwain, C.K. Strauss, C.K., T. Van Leuvan, Catch Share Design Manual, Volume 1: A Guide for Managers and Fishermen, second ed., (2010) Retrieved from http://fisherysolutionscenter.edf.org/sites/catchshares.edf.org/files/CSDM_Vol1_A_Guide_for_Managers_and_Fishermen.pdf , Accessed date: 24 April 2019http://dlc.dlib.indiana.edu/dlc/handle/10535/7071 (accessed December 25, 2018).
[36] E. Eythórsson, A decade of ITQ-management in Icelandic fisheries: consolidation without consensus, Mar. Policy 24 (2000) 483–492, https://doi.org/10.1016/S0308-597X(00)00021-X.
[37] F. Asche, M.T. Bjørndal, T. Bjørndal, Development in fleet fishing capacity in rights based fisheries, Mar. Policy 44 (2014) 166–171 https://doi.org/10.1016/j.marpol.2013.08.018.
[38] N.A. Dowling, C.M. Dichmont, M. Haddon, D.C. Smith, A.D.M. Smith, K. Sainsbury, Empirical harvest strategies for data-poor fisheries: a review of the literature, Fish. Res. (2015), https://doi.org/10.1016/j.fishres.2014.11.005.
[39] A.A. Rosenberg, K.M. Kleisner, J. Afflerbach, S.C. Anderson, M. Dickey-Collas, A.B. Cooper, M.J. Fogarty, E.A. Fulton, N.L. Gutiérrez, K.J.W. Hyde, E. Jardim, O.P. Jensen, T. Kristiansen, C. Longo, C.V. Minte-Vera, C. Minto, I. Mosqueira, G.C. Osio, D. Ovando, E.R. Selig, J.T. Thorson, J.C. Walsh, Y. Ye, Applying a new ensemble approach to estimating stock status of marine fisheries around the world, Conserv. Lett. 11 (2018) e12363, , https://doi.org/10.1111/conl.12363.
[40] R. Fujita, K. Karr, W. Battista, D.N. Rader, A Framework for Developing Scientific Management Guidance for Data-Limited Fisheries Un Marco para el Desarrollo de la Dirección Gerencia Científica para la Pesca de Datos Limitados Un Cadre pour L'élaboration de Principes de Gestion Scientifique des Pêch, n.d. http://nft.nefsc.noaa.gov/(accessed December 18, 2018).
[41] G. Mcdonald, B. Harford, A. Arrivillaga, E.A. Babcock, R. Carcamo, J. Foley, R. Fujita, T. Gedamke, J. Gibson, K. Karr, J. Robinson, J. Wilson, An indicator-based adaptive management framework and its application to data-limited fisheries in Belize, Mar. Policy 76 (2015) 28–37 https://doi.org/10.1016/j.marpol.2016.11.027618.
[42] T.R. Carruthers, A.E. Punt, C.J. Walters, A. MacCall, M.K. McAllister, E.J. Dick, J. Cope, Evaluating methods for setting catch limits in data-limited fisheries, Fish. Res. 153 (2014), https://doi.org/10.1016/J.FISHRES.2013.12.014 620 48–68.
[43] C. Chu, Thirty years later: the global growth of ITQs and their influence on stock status in marine fisheries, Fish Fish. 10 (2) (2009) 217–230 https://doi.org/10.1111/j.1467-2979.2008.00313.x.
[44] M. Makino, A short review of IQs/ITQs in foreign countries and a perspective for introduction of IQ/ITQ to the Japanese fisheries, Nippon Suisan Gakkaishi 75 (2009) 1087–1088, https://doi.org/10.2331/suisan.75.1087.
[45] Fisheries Agency of Japan, The grand design of fisheries and resources management in Japan, https://www.fra.affrc.go.jp/kseika/GDesign_FRM/FinalReport_eng.pdf, (2009) , Accessed date: 11 September 2018.
[46] J. Lynham, How have catch shares been allocated? Mar. Policy 44 (2014) 42–48, https://doi.org/10.1016/j.marpol.2013.08.007.
[47] J.E. Wilen, Spatial management of fisheries, Mar. Resour. Econ. 19 (2004) 7–19, https://doi.org/10.1086/mre.19.1.42629416.
[48] R. Fujita, C. Cusack, R. Karasik, H. Takade-Heumacher, Designing and Implementing Electronic Monitoring Systems for Fisheries: A Supplement to the Catch Share Design Manual, Environmental Defense Fund, San Francisco, 2018.
[49] R. Fujita, C. Cusack, R. Karasik, H. Takade-Heumacher, C. Baker, Technologies for Improving Fisheries Monitoring, Environmental Defense Fund, San Francisco, 2018.
[50] U.R. Sumaila, V. Lam, F. Le Manach, W. Swartz, D. Pauly, Global fisheries subsidies: an updated estimate, Mar. Policy 69 (2016) 189–193, https://doi.org/10.1016/j.marpol.2015.12.026.
[51] Y. Sakai, N. Yagi, U.R. Sumaila, Fishery subsidies: the interaction between science and policy, Fish. Sci. 85 (2019) 439–447, https://doi.org/10.1007/s12562-019-01306-2.
[52] G. Munro, U.R. Sumaila, The impact of subsidies upon fisheries management and sustainability: the case of the North Atlantic, Fish Fish. (2002) 233–250, https://doi.org/10.1046/j.1467-2979.2002.00081.x.
[53] U.R. Sumaila, D. Pauly, Catching more bait: a bottom-up re- estimation of global fisheries subsidies, Fish. Centre Res. Rep. 14 (2006) 114.
[54] N. Yagi, M. Ariji, Y. Senda, A time-series data analysis to examine effects of subsidies to fishery productions in Japan, Fish. Sci. 75 (2009) 3–11, https://doi.org/10.1007/s12562-008-0022-8.
[55] M. Makino, H. Matsuda, Co-management in Japanese coastal fisheries: institutional features and transaction costs, Mar. Policy 29 (2005) 441–450, https://doi.org/10.1016/j.marpol.2004.07.005.
[56] M. Makino, Fisheries Management in Japan: its Institutional Features and Case Studies, Springer Science & Business Media, 2011.