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Original article

Is the current rule of the TAC system for sharing out catch quotas appropriate for Japanese sardine fisheries?

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Introduction

Under output controls that restrict catch numbers, such as the Total Allowable Catch (TAC) system, deciding how to allocate the catch quota is often a problem [1]. In Japan, the TAC is divided into TAC managed by the Minister for Agriculture, Forestry and Fisheries and prefectural-governor-managed TAC [2]. Allocation ratios of these TACs are applied to share out the quotas; they are determined on the basis of the catch records for the preceding 3 years and are reevaluated every 3 years [3] (Fig. 1). The catch record is calculated as the

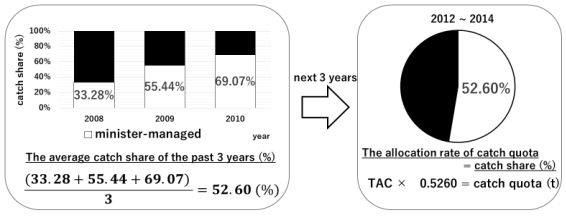

Fig. 1. Rationale behind the allocation procedure used under the TAC system in Japan [4].

amount caught by each fishery (i.e. the catch share) as a proportion of the total domestic catch. Therefore, if, for some reason, fishers do not catch as much as expected in a certain year, in theory they will have to exceed their usual catches in the remaining 1 or 2 years in order to maintain or increase their allocations of the catch quota over the next 3 years. Here, we examined whether or not a rational and competitive catch aimed at maintaining the allocation ratios of the catch quota was present in the Japanese sardine (*Sardinops melanostictus*) fishery managed by the Minister. Also, we quantitatively evaluated the influence of such catch behaviors on the future catch quota. Our results suggested that rational and competitive behaviors existed and helped to maintain the allocation ratios of the catch quota. At present, however, application of these behaviors is difficult in many fisheries, and a drastic fall in the ratios of allocation of catch quotas may adversely affect future catches. From the perspective of stability and equality it seems that we need to review the allocation rules for catch quotas.

Materials and methods

The quarterly catch share (%) of the Japanese sardine fishery managed by the Minister was calculated by using monthly sardine catch data from 2005 to 2014 [4]. Although the "annual" catch share has recently remained at around 50% or more, the "seasonal" catch share in the first quarter (Q1) has fluctuated markedly between 20% and 80%, because Q1 is the season when almost all Japanese sardine fisheries are just starting their catches (Fig. 2). Therefore, as a substitute for the Q1 data we used the average of the other seasonal data (Q2, Q3, Q4).

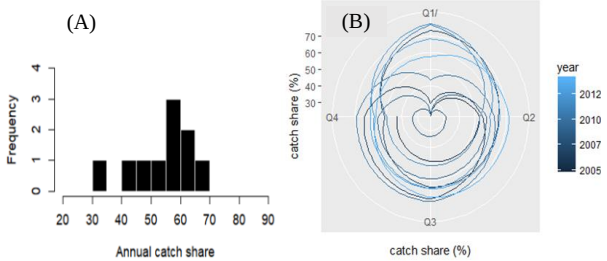

Fig. 2. (A) Histogram of the Minister-managed "annual" catch share of the Japanese sardine fishery. (B) Pole plot of "quarterly" (seasonal) catch shares. Note: (B) Q1 means First Quarter (the data for March) in this research; the Q4 data are for December and determine the "annual" data.

As the time series data were significantly autocorrelated with lag 1 (Fig. 3C, Table 1), we fitted the data to an autoregressive (AR (1)) model. Although we could not clearly reject the null hypothesis that the data had a unit root by the Dickey-Fuller test ($P > 0.05$; Table 1), spurious regression was avoided by using the AR model [5].

In addition, the annual catch shares in the 1 or 2 years after a poor catch year (e.g. 2008) climbed more steeply than the catch shares in other years (e.g. 2007 or 2013) (Fig. 3A). Therefore, we assumed that fishers made a greater catch effort when the average annual catch share during the period of calculation of the allocation ratio fell below 50%. To test this hypothesis,

a model assuming the occurrence of this competitive catch and a model not assuming it were prepared, and a dummy variable (0 or 1) was set for the former. Using R software (Version 1.0.136), we conducted a variable selection for each model, and the best model was selected by using the corrected Akaike's information criterion (AICc). When the coefficient of the dummy variable was significantly more than 0, we performed a quantitative evaluation of the effect of competitive catch on future catch.

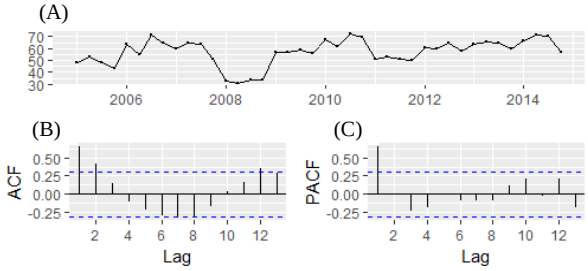

Fig. 3. (A) Quarterly data for catch share (%) of the Minister-managed sardine fishery from 2005 to 2014 [4, 5]. (B) and (C), ACF (autocorrelation function) and PACF (partial autocorrelation function), respectively, for the above data. Note: (A) Each set of Q1 data was substituted by the average of the other seasonal data (Q2, Q3, Q4).

Table. 1. Results of Ljung-Box and Dickey-Fuller tests

Test	*P* - value
Ljung - Box test	$2.167\ e^{-5}$ (< 0.05)
Dickey - Fuller test	0.1287

Results

As a result of model selection, the AR (1) model assuming competitive catch was selected as the best model and the explanatory variable term (X) was significantly more than 0 (Table 2). According to the best model, the estimated mean increase in catch share from 2008 to 2010 as a result of competitive catch was 7.578% (SE: 2.477); this was equivalent to a 57,741-ton gross increase in the catch quota over the next 3 years (2012– 2014). Also, compared with the simple AR (1) model, the best model with X forecast better catch shares in 2015 and 2016 (Fig. 4).

Table. 2. Results of model selection and estimated parameters for AR (1) model and AR (1) with explanatory variable X

Model	Term	Estimate	SE	*P*-value	AICc
AR (1)	Intercept	20.39	7.228	$7.560\ e^{-3}$	288.2
	AR (1)	0.6421	0.1243	$7.858\ e^{-6}$	
AR (1) + X	Intercept	18.96	6.560	$6.397\ e^{-3}$	281.2
	AR (1)	0.6141	0.1129	$3.591\ e^{-6}$	
	X	7.578	2.477	$4.109\ e^{-3}$	

Discussion

We confirmed that the competitive catch made to maintain catch share influenced the future catch quota and was quite reasonable. To maintain future catch quotas, it is important for this type of flexible catch to be possible. However, for some "passive" fisheries, such as those using fixed shore nets, it is difficult to catch flexibly. Also, if the catch were to decrease

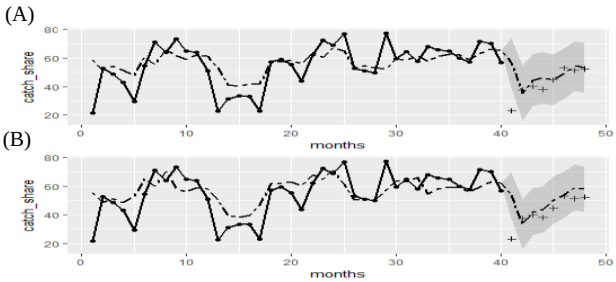

Fig. 4. Catch share forecasting in 2015 and 2016 (from the 41st to the 48th month). (A) AR (1) model; (B) AR (1) + X model. Solid line and "+" symbol show real catch share data; broken line shows predicted catch shares; gray zone shows 95% confidence interval of estimation. Note: Mean squared error for each model during the prediction interval was calculated at (A) 157.1 and (B) 140.1.

unexpectedly in the last (third) year of the period used to calculate catch records, there would be no hope—even for a purse seine fishery or trawl fishery—to maintain the catch share. In short, in cases where flexible catch behavior is not possible there is a risk that the future allocation ratio of the catch quota will unintentionally be reduced. In fact, Mie Prefecture and a number of others requested and acquired additional allocations in 2016 and 2017 because they expected shortages in the catch quota [6]. To achieve the quota allocation desired, stability and equality of allocation size need to be considered more seriously. As Brams and Taylor [7] said, an "equitable" allocation rule does not always assign equal shares to each agent; instead, shares may be allocated in proportion to each agent's entitlements (needs, demands, or claims). Taking these factors into consideration, we should continue to examine the validity of the current rules, including the period of calculation of the catch record and the update frequency of the allocation ratio.

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