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CHARACTERISTICS OF HISTORICAL POPULATION DYNAMICS OF TEMPERATE TUNAS IN THE NORTH PACIFIC AND IMPLICATIONS FOR MANAGEMENT

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Characteristics of Historical Population Dynamics of Temperate Tunas in the North Pacific and Implications for Management

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Summary

We examined long-term time series of stock status for the temperate tunas Pacific bluefin and albacore in the north Pacific, and characterized temporal changes in the stock status of both species through comparison with tropical tunas in the Western and Central Pacific. The temperate tunas appear to have historically experienced considerable fluctuation in stock status over a long period of time, whereas the stock status of tropical tunas with shorter exploitation histories are characterized by consistent decreases in stock sizes and increases in catches. Based on these features, we discuss appropriate management strategies such as the identification of candidate limit reference points (LRPs) for each tuna stock in the Western and Central Pacific, and suggest that LRPs based on historical stock sizes are worthy of consideration for temperate tunas in the North Pacific.

Introduction

In developing appropriate fisheries management measures, demographic features such as life history strategies and exploitation histories of target species to be managed should be taken into account. Hilborn and Stokes (2010) discussed the definition of “overfished” and warned that biological reference points (RPs) based on B_{MSY} and unfished biomass (B_0) are arbitrarily used for fisheries management despite difficulties of interpretation and estimation of these quantities. For example, it is known that in the case of fishes with high productivity, yields that are close to MSY (for example, “Pretty Good Yield”) can be obtained over a broad range of stock sizes (i.e. even when stock size is lower than B_{MSY}; Hilborn 2010). As an alternative they recommended using historical stock sizes as target or limit RPs, because these RPs have the advantages of being based on species-specific experience, are easily understood, and are not subject to uncertainties in model assumptions. Therefore, it is considered valuable to review the historical stock status of target species when determining management strategies such as RPs.

Recently, it has been widely accepted that ocean ecosystem dynamics are influenced by climatic and oceanographic factors as well as by fish harvesting (Hare and Mantua 2000). In particular, long-term variability in abundance on the scale of decades or even centuries (often called regime shifts;

Kawasaki 1983) has received considerable attention in the management of small pelagic fishes such as sardines and anchovies in the north Pacific (Baumgartner et al. 1992, Yatsu et al. 2008).

Similarly, large pelagic fishes such as tuna and tuna-like species are thought to be influenced by long-term environmental oscillations in addition to temporal changes in fishing activities. Ravier and Fromentin (2001) analyzed a long-term time series of over 300 years for Atlantic bluefin tuna captured in traditional Mediterranean and eastern Atlantic trap fisheries. They found fluctuations of about 15-30 years superimposed on long-term cycles of about 100-120 years (Fig. 1). Regarding the potential mechanism that produces the oscillations, they considered that long-term trends in water temperature influence migration routes to the spawning grounds in the Mediterranean and consequently change the species' vulnerability to traps (Ravier and Fromentin 2004). Dufour et al. (2010) also reported that migration phenology and spatial distribution of north Atlantic albacore and eastern Atlantic bluefin tunas was changed by the North Atlantic regime shift (particularly notable in the 1988-1989 regime shift). Currently these species reach the Bay of Biscay a few weeks earlier than they did several decades ago. These studies of temperate tuna species in the north Atlantic indicate that stock status might fluctuate on multi-decadal scales even without changes in fishing intensity.

Here, we review long-term temporal variability in the stock status of Pacific bluefin (PBF) and northern albacore (ALBN) tunas in the North Pacific, and characterize them through comparison with tropical tuna species in the Western and Central Pacific. We begin with a review of the scientific literature relating to long-term trends in the stock status of these two species. Then, we analyze long-term time series of recruitment-related productivity and abundance as estimated by the latest formal stock assessments conducted by the ISC (International Scientific Committee for Tuna and Tuna-like Species in the North Pacific Ocean). Finally, we characterize temporal changes in the stock status of temperate tunas through comparison with tropical tunas, and discuss implications for management strategies, particularly for limit reference points (LRPs).

In preparing this paper, we recognize the value of previous discussions regarding RPs for WCPFC stocks at prior WCPFC Scientific Committee meetings. However, we also believe that it is valuable and constructive to present additional ideas on other RP candidates potentially applicable to the Northern stocks of the WCPFC which have not yet been discussed at the SC meetings.

Features of population dynamics of temperate tunas in the North Pacific

- Review of scientific literature

PBF is known from shell mound surveys in Japan to have been exploited for thousands of years

(Kishinouye 1911). Ito (1961) reconstructed long-term catch trends of PBF since the 16th century based on ancient documentation of catch levels of set nets along the Japanese coast (Fig. 2). Although these data are somewhat descriptive and thus the catch estimates are qualitative, this research demonstrated that there were large catches in the late 17th century, the early 19th century and the early 20th century. This indicates that the PBF catch was cyclical with periods of about 100 years. Ito (1961) also suggested the existence of a cycle of about 30 years in addition to the 100-year oscillation.

ALBN were caught by US fisheries off southern California for canning as early as 1903 (Anderson et al. 1953). The Japanese pole-and-line fishery started in the 1920s and by the start of the Second World War annual catches had exceeded 100,000 t (Suda 1959). Au and Cayan (1998) analyzed long-term records of American and Japanese catches from 1911 to 1993 and found evidence of an association between catches and decadal-scale climatic changes. Periods of decreasing trends in catches (1926-1947 and 1976-1989) coincided with periods of increased intensity of the Aleutian Low (i.e. more severe winters in the western and central North Pacific).

- Time-series analysis of productivity and abundance of PBF and ALBN

We analyzed a time series of PBF and ALBN recruitment-related productivity and abundance for 1952-2007 (for PBF) and 1966-2010 (for ALBN) to reveal possible mechanisms for the long-term fluctuation of stock abundance. Here, we examined four stock indices that characterize population dynamics and stock status: (1) recruitment per spawner (RPS); (2) recruitment; (3) total stock biomass; and (4) spawning stock biomass (SSB). These were estimated in the latest stock assessments for both stocks as conducted by the ISC (ISC 2010a, 2011). In addition, the possibility of regime shifts was statistically examined for RPS and recruitment using the method of Rodionov (2004, 2006). The detailed methodology used to detect regime shifts is described in the Appendix. In the North Pacific, some climatic factors such as the El Niño-Southern Oscillation (ENSO) and the Pacific Decadal Oscillation (PDO) interactively govern the oceanographic conditions (Hare and Mantua 2000). Since the 1950s, climatic regime shifts have been identified in the North Pacific in 1957-58, 1970-71, 1976-77, and 1988-89 (Yasunaka and Hanawa 2002, King 2005).

Our results revealed that decadal fluctuations were apparent in all stock status indices for PBF during the 60 years analyzed (Fig. 3). The magnitude of fluctuations, including annual variation, was large. In particular, there was more than a 20-fold difference between the maximum and minimum values for RPS. Similarly, ALBN showed long-term variability over an approximately 20-year cycle for the all indices (Fig. 4). Although the variability in the ALBN time series was less than that in the PBF time series (this might be partially caused by the fact that the ALBN time series was shorter), the maxima were about 2-3 times larger than the minima in all indices.

Statistically significant regime shifts were detected in RPS (in 1972 and 1992) for PBF, and in RPS (in 1988 and 1995) and recruitment (in 1978 and 1988) for ALBN (Figs 3 and 4). The timing of stock status shifts (except for 1995) closely matched years of climatic regime shifts. This synchronism suggests a considerable influence of the oceanographic environment on productivity and stock status of both species, but the impacts of other factors such as fishing mortality cannot be dismissed. Although PBF recruitment appeared to have regime shifts (Fig. 3), the shifts were not statistically detected, probably because the annual recruitment variability was relatively large compared to the magnitude of the apparent regime shifts.

Inagake and Uehara (2003) showed significant temporal correlations between recruitment in these two species and climatic variability indices such as ENSO and PDO. Their detailed analysis suggested that as water temperatures in the feeding grounds in winter and the spawning grounds in spring were higher, there was higher recruitment probably due to improvement of parental quality and an increase in juvenile survival.

Comparison to tropical tunas and implication for management

We then compared population dynamics features and exploitation histories between temperate tunas (PBF: Pacific bluefin, ALBN: northern albacore) in the North Pacific, and tropical tunas (YFT: yellowfin, BET: bigeye, ALBS: southern albacore, SKJ: skipjack) in the Western and Central Pacific. This comparison is important for understanding appropriate biological reference points (RPs) for each stock. Figure 5 shows five-year moving average indices of (a) RPS, (b) recruitment, (c) total biomass, (d) SSB and (e) catches from the latest stock assessment for the two northern stocks (ISC 2010a, 2011) and the four southern stocks (Davies et al. 2011, Hoyle et al. 2011, Langley et al. 2011, Hoyle et al. 2012).

- Tropical tunas

The history of exploitation is generally shorter in the tropical region than in the temperate region. Industrial fisheries in the tropical region were initiated around 1940 by Japanese pole-and-line and longline fisheries, and expanded rapidly after the Second World War. The fishery was then further developed by the start of large-scale operations of distant water purse seiners (Fig. 5e). In contrast to the temperate tunas, catches have been increasing in most of the stocks. Stock abundance (total biomass and SSB) is estimated to have declined consistently during the expansion of the industrial fishery and then to have been maintained at a constant level for some stocks (e.g., YFT and BET; Fig. 5c,d). Recent estimates of abundance are close to or above the B_{MSY} level in most of the tropical tuna stocks. This temporal pattern of stock size indicates that these stocks have not experienced considerable fluctuations in stock status or that such historical fluctuations have not yet been clearly identified. In this “one-way trip” situation, it might be difficult to find a stock status level below which “bad things happen” (i.e. a LRP; Harley et al. 2012), because reliable historical information that covers a wide range of stock status is limited. Therefore, it might be reasonable to define a species-specific LRP for tropical tunas based on discussions at WCPFC SC8 held in Busan in 2012 (WCPFC 2012).

- Temperate tunas

In contrast, as mentioned in the previous section, temperate tunas have long history of exploitation and unlike tropical tunas, catches after the 1950s are relatively stable within a narrow range (Fig. 5e). On the other hand, stock status for temperate tunas shows considerable fluctuation over multi-temporal scales (from a year to decades; Fig. 5a-d). For these temperate species, long-term stock status trends could suggest some levels of stock size that would be prudent to avoid (Harley et al. 2012). For example, a stock size below which significant reduction in recruitment occurs (recruitment overfishing) can be detected when long-term time series of stock sizes and recruitments are available (Hilborn and Stokes 2010). Therefore, it would be reasonable to define LRPs for temperate tuna stocks based on historical stock status. Using this approach, Kai et al. (2012) theoretically demonstrated that F_{loss} (the fishing mortality that produces the RPS associated with the historically lowest SSB (B_{loss})) outperforms F_{MSY} as a LRP in some situations.

Fundamentally, LRPs can be regarded as thresholds to avoid recruitment overfishing. For fish stocks with high productivity under low SSB (i.e. high “steepness” in the stock-recruitment relationship; Kai et al. 2012), recruitment overfishing is very unlikely to occur (Hilborn 2010). Temperate tunas in the North Pacific are thus unlikely to suffer from recruitment overfishing because they are considered to have very high steepness (Mangel et al. 2010; Iwata et al. 2011). The long history of sustainable exploitation of these tuna stocks appears to support this theory. Therefore, LRPs based on historical stock sizes could play an essential role for these stocks in avoiding recruitment overfishing.

An LRP based on a similar concept, i.e. $F_{SSB\text{-}ATHL}$ (the fishing mortality which will maintain SSB above the average level of the ten historically lowest points (SSB_{ATHL})), has already been used as the interim management objective for the ALBN. To reduce the risk associated with uncertainty in estimating historical biomass, the ALB working group of ISC agreed to use the average of the ten lowest annual points from a time series spanning about 40 years (ISC 2010b). Another LRP called B_{limit} (the minimum stock biomass which will ensure an appropriate amount of recruitment) has been officially implemented for domestic marine resources in Japan for about 15 years (Kanaiwa 2012). Japanese stakeholders including managers and industries are familiar with this management approach and find it easy to understand because it is based on past experience.

Information presented in this document suggests that LRPs based on historical stock sizes can be possible options for temperate tunas in the North Pacific. This is also supported by theoretical analysis (Kai et al. 2012) and from the perspective of ease of management implementation (Kanaiwa 2012). We consider that it is important to evaluate the advantages and disadvantages of LRPs, including historically-based LRPs, for each stock from multiple viewpoints such as robustness to estimation uncertainties and understandability by stakeholders (Hilborn and Stokes 2010).

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Figure 1. Long-term series of trap catches of Atlantic bluefin tuna in the eastern Atlantic and Mediterranean (Ravier and Fromentin 2001).

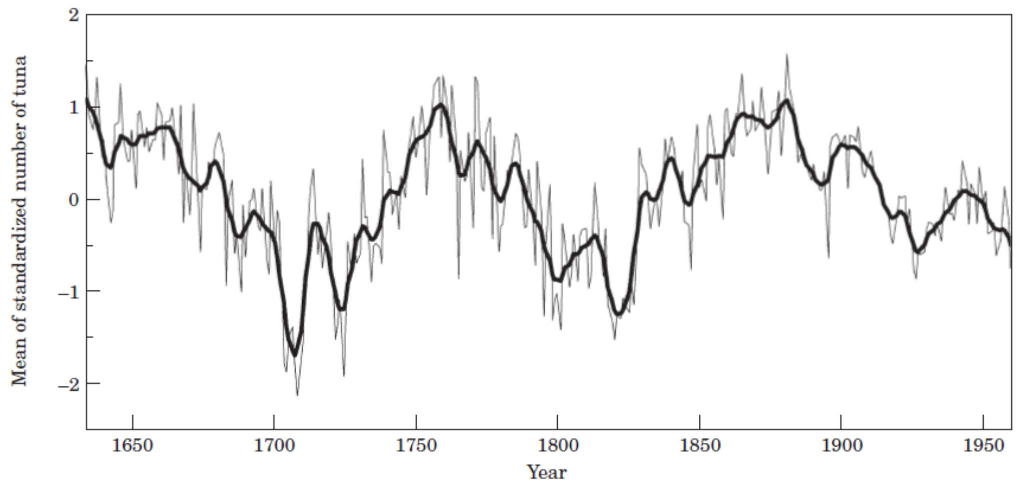


Figure 2. Long-term catch series of Pacific bluefin tuna in Japan estimated from ancient documentation (Ito 1961; the horizontal and vertical axes indicate the year and the level of catches, respectively).

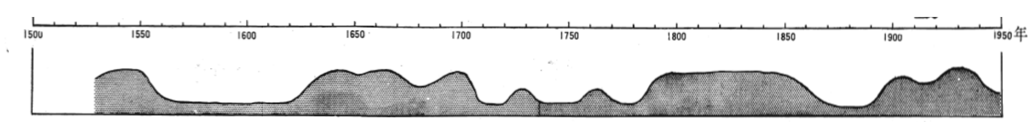


Figure 3. Time series of stock status from the ISC stock assessment (ISC 2010a) and catches of Pacific bluefin tuna (PBF). Red triangles in the upper panel indicates years in which regime shifts were statistically detected.

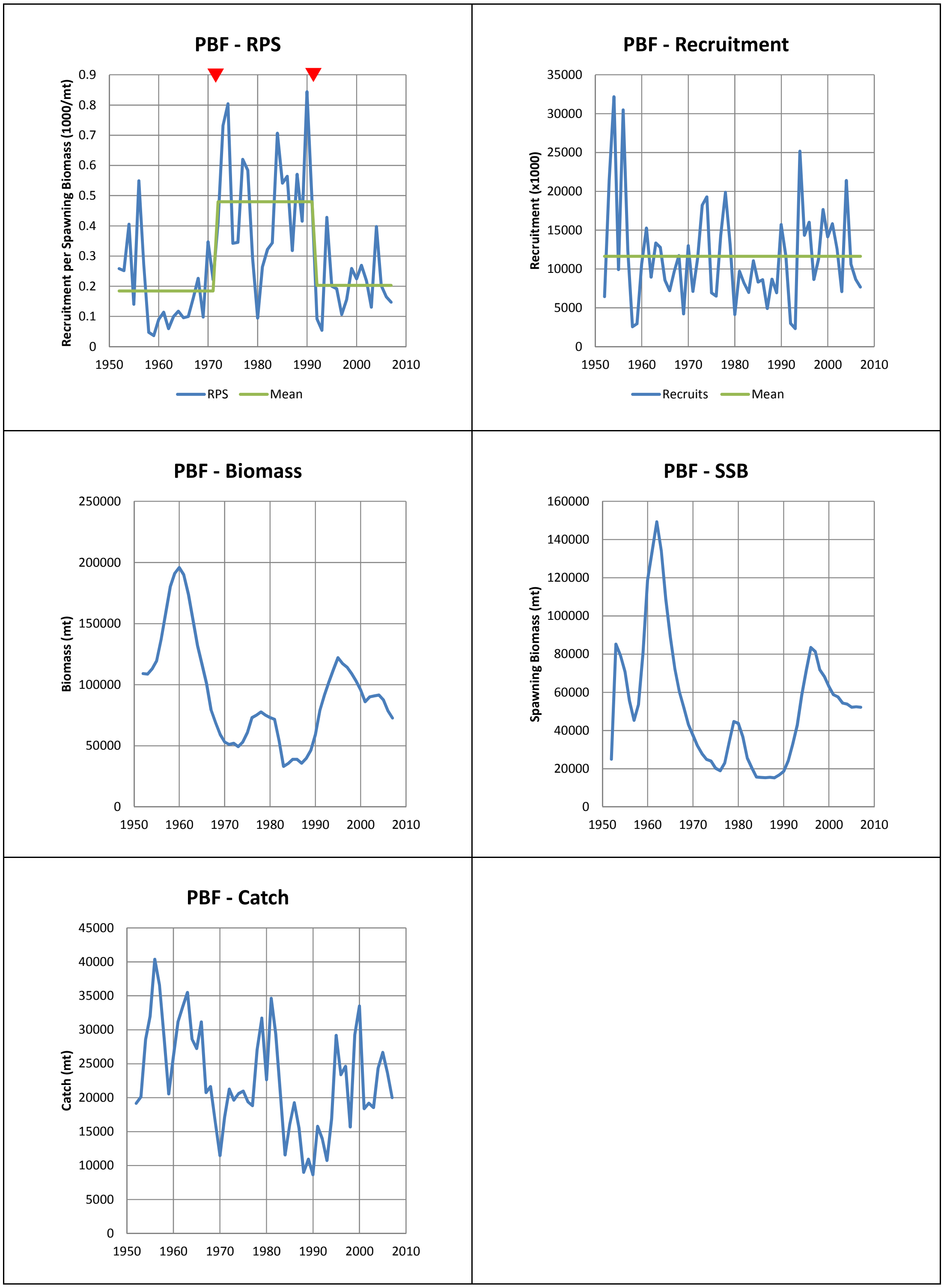


Figure 4. Time series of stock status from the ISC stock assessment (ISC 2011) and catches of northern albacore (ALBN). Red triangles in the upper panels represent years in which regime shifts were statistically detected.

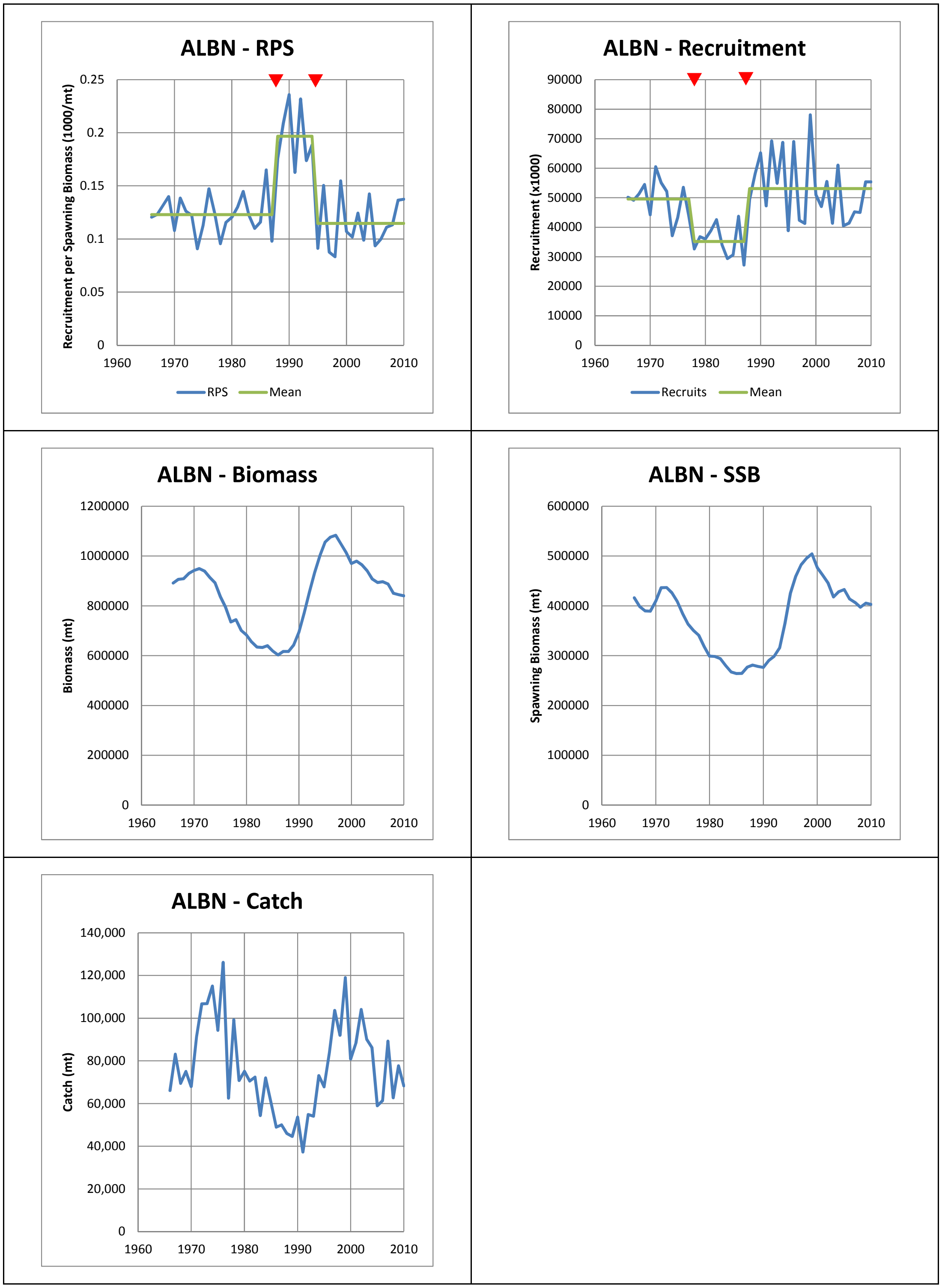
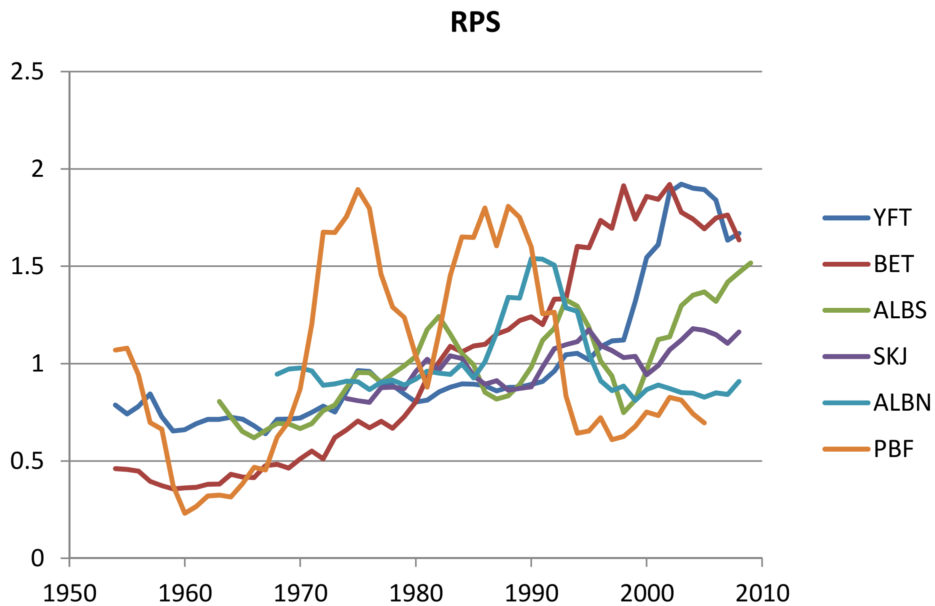
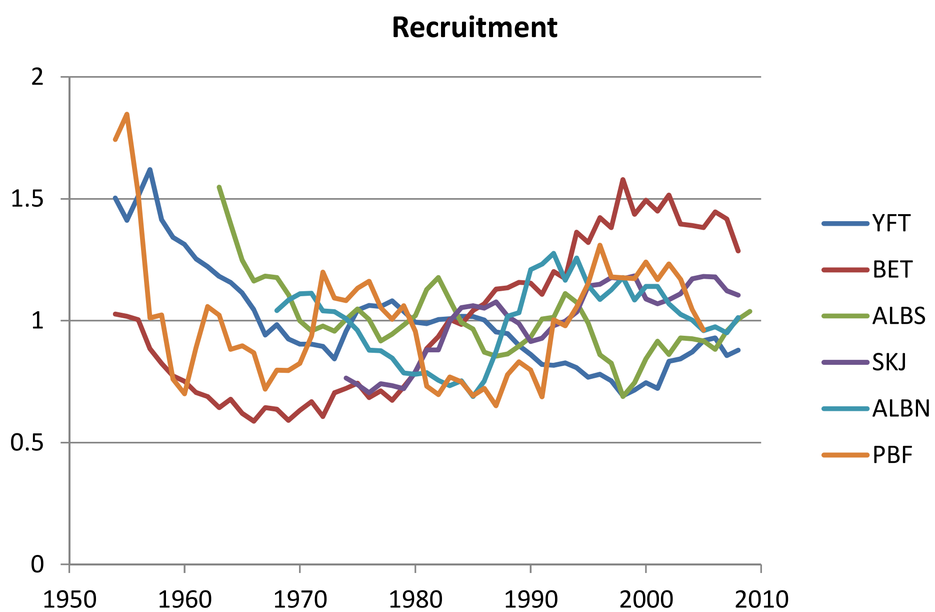


Figure 5. Historical time series of stock status and catches of four tuna stocks in the Western and Central Pacific and two tuna stocks in the North Pacific (relative to the average of each stock).

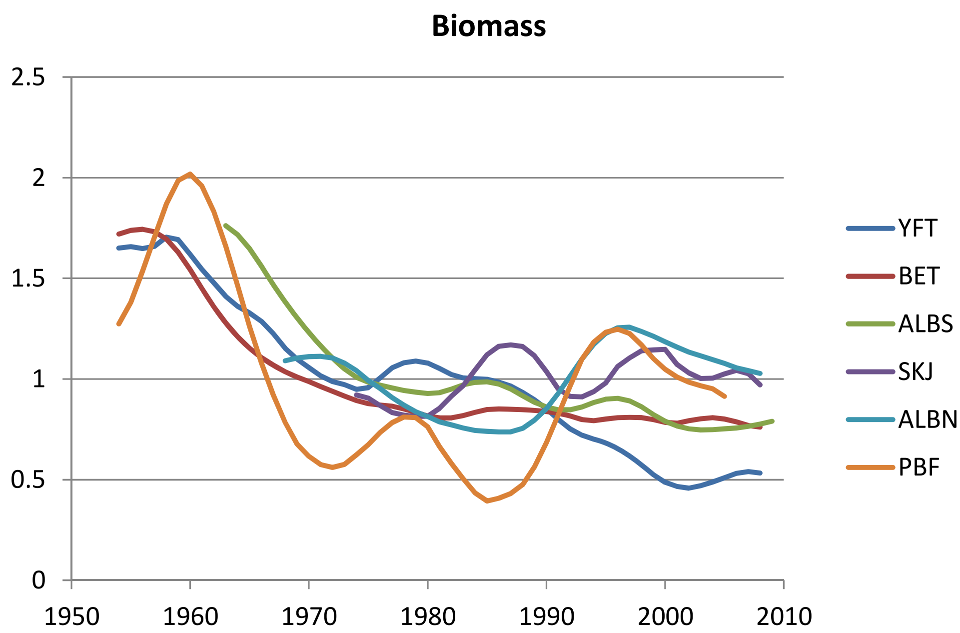
(a) RPS (recruitment per spawning stock biomass)



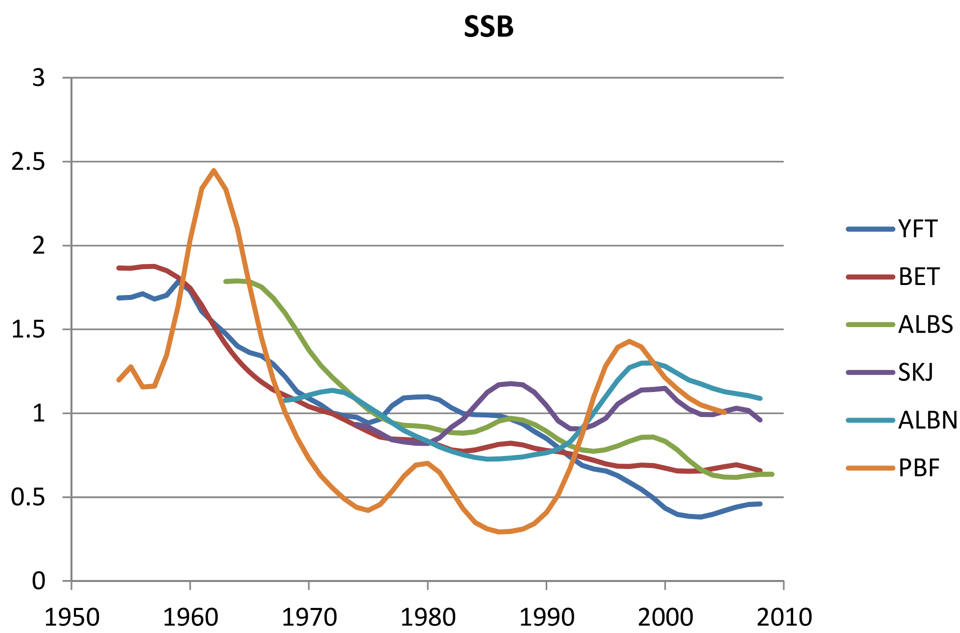
(b) Recruitment



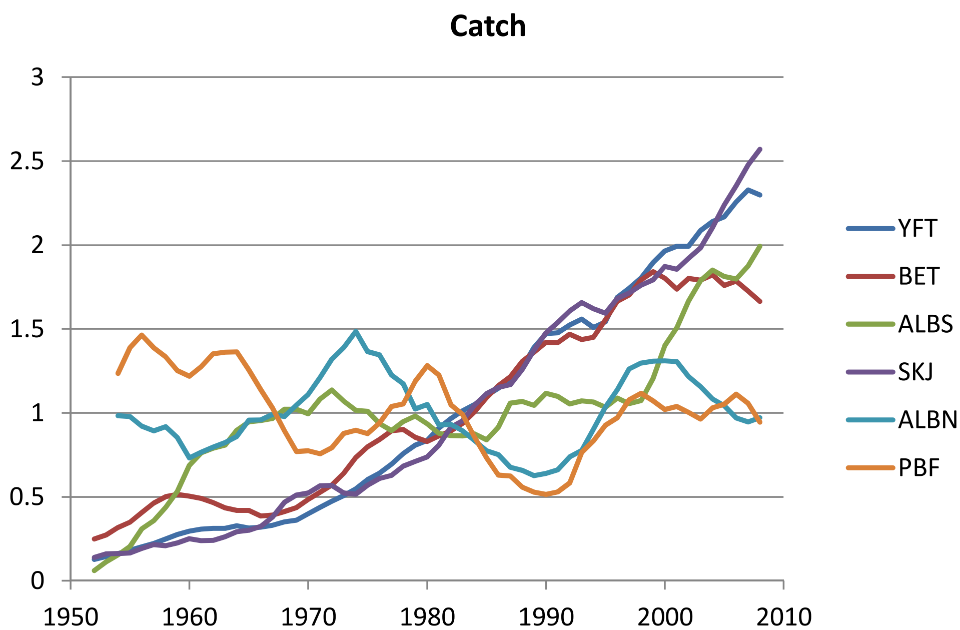
(c) Biomass



(d) SSB (spawning stock biomass)



(e) Catches



Catch
3
2.5
2
1.5
1
0.5
0
1950
1960
1970
1980
1990
2000
2010
YFT
BET
ALBS
SKJ
ALBN
PBF

Appendix

Yatsu et al. (2008) states that among several methods for the detection of regime shift years in time series analysis, only that of Rodionov (2004, 2006) can be applied to potential recent shifts. This method was initially based on a sequential *t*-test that can assess the probability of a shift in real time, and was further expanded to exclude serial autocorrelation (red noise) by adopting a prewhitening technique (Rodionov 2006). We used STARS version 3.2 downloaded from http://www.beringclimate.noaa.gov/regimes/ to implement this analysis. "Cutoff length" was set at 10 years and the level of statistical significance was set to 0.05.