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Aims and Scope

Management, aquaculture, taxonomy, behavior, stock identification, genetics, nutrition, physiology; these are just a few of the subject areas included in the discipline of fisheries science. Fisheries science encompasses both finfish and an array of aquatic invertebrates. Included are species of economic and recreational importance, those that may be indicators of environmental health, and some that are prized for their natural beauty. *Reviews in Fisheries Science* provides a forum for the publication of reviews on the array of subjects that make up the discipline, and gives the reader the most recent information on the issues of today. In addition, the journal publishes articles of an experiential or historical nature. Fisheries scientists in academia, state and federal natural resources agencies, and in the private sector will find useful articles in each edition of *Reviews in Fisheries Science*.

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Toward Sustainable and Responsible Tuna Fisheries

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ABSTRACT: The 'Code of Conduct for Responsible Fisheries' adopted by the Food and Agriculture Organization (FAO) of the United Nations (UN) in 1995 (FAO, 1995) is discussed. Implementation of this Code in the tuna fisheries is highlighted because compliance with this Code is the fundamental condition for tuna fishing nations to be able to continue to fish and to sustain tuna fisheries. Four important subjects in the Code are discussed extensively: resource analyses, mitigation of bycatch, strategies for management and stock propagation. The current situation regarding adherence to the Code is reviewed. Then problems and difficulties with implementation are summarized and some potential approaches, ideas and ongoing attempts are introduced and discussed. Throughout, it is realized that mitigation of bycatch is the most serious task for responsible and sustainable tuna fisheries. Several successful attempts have been made to mitigate bycatch of some species. It is likely to be possible to solve bycatch problems for other species in the near future because of significant efforts by tuna fishing nations toward this goal. In addition, it is realized that data collection systems and tuna resources analyses are improving, management strategies are evolving, and stock propagation is promising.

KEY WORDS: uncertainty, mitigation of bycatch, fishery management, Indian Ocean, southern bluefin tuna, yellowfin tuna..

I. INTRODUCTION

A. BACKGROUND

World fisheries in the 1970s were characterized by peak levels of distant water fisheries for salmon, tuna, whales, and groundfish. Distant water fisheries were pursued with few restrictions, such as catch and effort limitation or regulation of fishing method, because these were open access fisheries. Not much attention was

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paid to marine ecosystems either. However, after 200-mile Exclusive Economic Zones (EEZ) and Fishery Conservation Zones were widely implemented in the mid-1970s, and after the International Whaling Commission (IWC) adopted its moratorium in 1982, interest increased among distant water fishing nations and coastal states concerning effects of fisheries on marine ecosystems. Since then, various environmental and ecosystem related fisheries issues have been raised and discussed. Taking into account such matters, world opinion, especially in North America, Europe, and Oceania, views open ocean fishing as a threat to marine ecosystems. Therefore, the UN (representatives of the people in the world) have been asking or requesting high seas fishing nations (as well as coastal nations) to achieve responsible fisheries by taking care of marine ecosystems, especially with respect to endangered and protected species.

The FAO of the United Nations originally raised the concept of 'responsible fisheries' in 1991 because FAO plays an important role in promoting international understanding about responsible conduct of fishing operations. After 1991, FAO held several meetings on the topic of responsible fisheries. In 1995, the Code of Conduct for Responsible Fisheries was agreed by member countries of the FAO (FAO, 1995). The Code advises fishing states to be responsible for various aspects when fishing occurs. For high seas fishing nations, the following conditions are required: (1) to use ecologically safe fishing methods for the marine ecosystem, (2) to prevent over fishing by applying optimum fishing efforts, (3) collect and provide accurate information on fish and fisheries, (4) to conduct appropriate international fisheries management based on the scientific information and analyses, (5) safe fishing operations, and (6) to follow the international fishing regulations and treaties. This Code is a voluntary instrument, thus it does not require ratification. The FAO is now in the process of drafting guidelines for implementation of the different articles. These, as well as the Code, are being given wide circulation in industry and government levels (*personal communication with* D. Ardill, FAO Fishery Statistician).

If fishing nations do not pursue this Code, world opinion appears to be in favor of restricting or prohibiting fisheries in the future. At present, for the high seas commercial fishing community, tuna fisheries (longline, purse seine, pole, and line and others) are the major fisheries producing tuna products that are utilized by many nations. Hence, it is seen as an essential and an urgent task to implement responsible tuna fisheries in order to sustain fisheries in the open ocean. At present, how this can be done is the subject of serious discussion, research, and examination.

B. OBJECTIVE AND OUTLINE

This article aims to review problems in implementing sustainable and responsible tuna fisheries and also to explore possible and potential methodologies to improve tuna management to solve problems raised. The Code addresses a variety of important topics. The following four aspects, most relevant to sustainable and responsible tuna fisheries, are discussed, i.e., resource analyses, mitigation of bycatch, strategies for management, and stock propagation. Tuna species highlighted in this article are five commercially important species: yellowfin tuna (*Thunnus albacares*), bigeye tuna (*Thunnus obesus*), albacore (*Thunnus alalunga*), northern bluefin tuna (*Thunnus thynnus*), and southern bluefin tuna (*Thunnus maccoyii*). Distribution of these five species is shown in Figure 1. Examples are taken mainly from Indian Ocean tuna fisheries and southern bluefin tuna fisheries, which are somewhat limited, but can become practical references for other tuna species and other waters.

II. RESOURCE ANALYSES

Because resources analyses (stock assessments) are the primary keys for tuna fisheries management, accurate and reliable stock assessments are required for implementing sustainable and responsible tuna fisheries. However, as frequently experienced, it is difficult to estimate accurate population parameters due to the uncertain quality of available tuna fisheries data and/or also due to effects of changes in ecosystems. Consequently, accurate statuses of tuna stock have been hard to elucidate. In this section, problems in data and stock assessments are reviewed. Then discussion is made of potential methodologies to improve stock assessments to implement sustainable and responsible tuna fisheries.

A. DATA

1. Data Collection

In the last thirty years the quality of (tuna) fisheries data remains generally uncertain, while stock assessment techniques have significantly improved and become increasingly sophisticated. (Sissenwine and Kirkley, 1984). At present, it usually takes 1 to 2 years to compile and publish the official tuna fisheries statistics in tuna fishing nations. For full utilization of assessment models and in order to conduct a near real-time stock evaluation, it is necessary to increase accuracy of tuna fisheries information and to update and speed data collection systems through close monitoring of data collection activities. Discussions of how such monitoring can be implemented are made below for both developing and developed countries.

In the developing countries, tuna fisheries statistics are obtained using the statistical collection systems established many years ago by foreign experts and not updated yet in many countries, for example, Maldives, Sri Lanka, India, Bangladesh, Thailand, and Indonesia in the Southeast and the South Asian region (Nishida and Sivasubramaniam, 1987). Technical assistance from bilateral sources such as the overseas development assistance (ODA) from developed countries or international agencies such as FAO and Asian Development Bank (ADB) is urgently needed to update the fishery data collection system for tunas. The main obstacles to improvement of the collection system are lack of budget to restructure the whole system and also to increase sampling frequencies. Without strong initiatives for these tasks and sufficient funds, the situation remains unchanged because there seems to be no other alternative approaches. If these tasks are conducted successfully, the accuracy of the stock assessments will be essentially increased. If the current situation persists, stock assessment regardless of the model, used remains unreliable, especially when the proportion of tuna catch in a region caught by developing countries is large. In

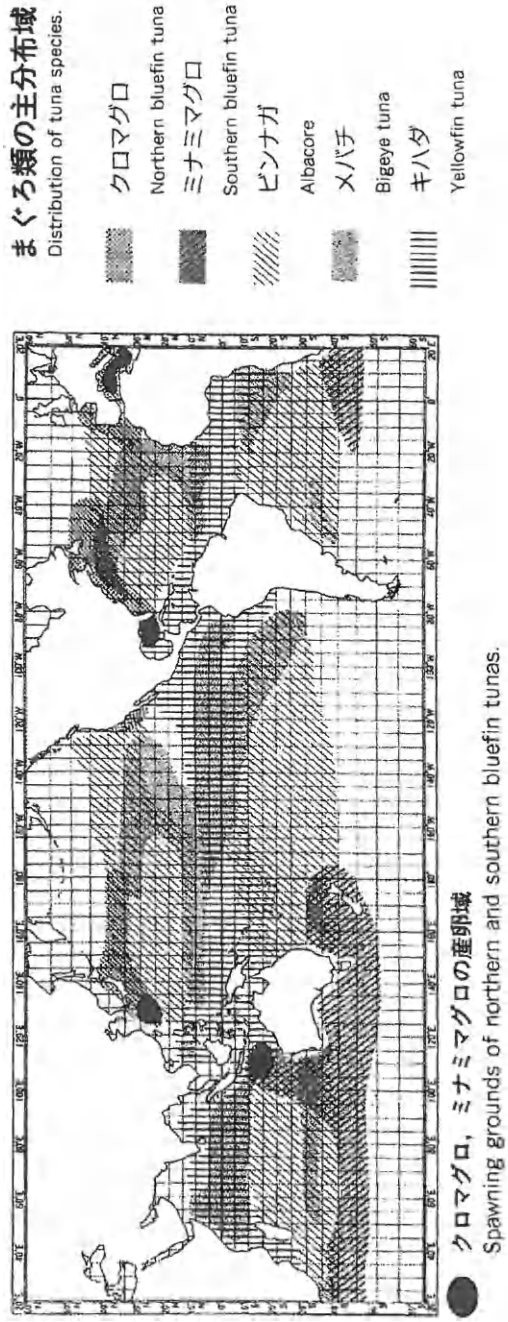

FIGURE 1. Distribution of five major tuna species. (Source: National Research Institute of Far Seas Fisheries.)

the Indian Ocean, for example, around 40% of catch of major tuna species is made by the developing countries in 1994 (IPTP, 1996).

For developed countries, reporting causes delay because of the long trip duration (up to 2 years in the case of open ocean longliners) and the processing time. This problem must be solved in order to conduct real time stock assessment. Various types of monitoring programs have proven effective in obtaining more accurate data for large-scale commercial tuna fisheries (Anon., 1993 and 1994a). In recent years, three monitoring programs are being conducted for Japanese longline tuna fisheries, that is, Real Time Monitoring Program, (RTMP), Observer Program, and Satellite-based Fisheries Management System. The first two programs have developed successfully and have been providing accurate and timely information, while the last program is partially implemented.

2. *Catch Reporting*

One of most serious problems in tuna fisheries statistics is unreported catch by countries who are not members of international tuna organizations. In the southern bluefin tuna case, for example, Taiwan, Indonesia, and Korea are non-member countries of the Commission for the Conservation of Southern Bluefin Tuna (CCSBT). It is estimated that these countries exploit about 10 to 15% of total southern bluefin catch in recent years (Nishida, 1993b). Lack of information from these fleets causes serious uncertainties in stock assessment.

A second problem is the double counting of the catch or nonreporting of the catch. In recent years, developed and developing countries conduct joint venture tuna fishing operations in the EEZ of developing countries. Because the two countries jointly catch tuna, they sometimes report the catch in national statistics in each country, which causes double reporting of statistics, or they do not report at all because each country assumes that the other county reports the data. These problems need to be more closely supervised by international tuna organizations and relevant tuna fishing nations.

3. *Ecological Data*

Various ecological factors affect mortality, distribution, and density of pelagic species, especially in the early life stages. Hence, it is necessary to include these factors in the resource analyses. For tuna, the following factors affect horizontal and vertical distribution and/or natural fishing mortality: surface sea temperature (SST), moon phase, thermocline, bottom topography, salinity, chlorophyll, El Niño, and distribution of prey species. Some analyses have incorporated these factors in the stock assessment models, for example, Nishida (1993c). One project sponsored by the National Research Institute of Far Seas Fisheries (NRIFSF) of Japan plans to acquire physical environmental information by attaching micro-data loggers to the Japanese longline gear, so that depth-specific temperature and salinity information can be collected worldwide. In addition, geopotential height data for more than 40 years are available from the World Meteorological Organization and the global geographic distribution of the longline tuna catch data also have been available for more than 40 years in Japan, Korea, and China (Taiwan). These data sets can be useful in studying relationships between climate and tuna fisheries and for feedback into stock assessment models.

B. STOCK ASSESSMENT

1. Catchability Coefficient

One of the most fundamental and important parameters for tuna stock assessment models is the catchability coefficient, "q". In tuna resource assessments, longline fisheries statistics are used frequently as the key information because more than 40 years of the data are available globally. In analyzing longline data, the catchability coefficient is usually assumed to be constant (homogeneous). However, due to technological innovation over time, the efficiency of fishing gear and vessels has improved. Therefore, it is clear that the quality of effort must be heterogeneous over this long period. This changes the homogeneity of the catchability coefficient, which then affects catch-per-unit-effort (CPUE), for example, and alters the results of CPUE-based stock assessments. Under such circumstances, investigation into the evolution of fishing efficiencies in the Japanese longline fleet is strongly desired, so that the catchability coefficient might be able to be quantified and modeled in some mathematical functions for use in the assessment models.

2. CPUE

CPUE is used as the basic population information to estimate the abundance index of tuna resources. It is also utilized in various assessment models. However, nominal CPUE is usually biased by various factors. To estimate unbiased CPUE, factors affecting nominal CPUE must be investigated and statistically significant factors need to be taken into account. In CPUE standardization for tuna longline data, the general linear model (GLM) has been widely used (Punsly and Nakano, 1992; Hearn et al., 1994; and many others). In the GLM analyses, monthly or quarterly data by latitude and longitude block area (e.g., 5 × 10 degrees square areas) are used, which are compiled by accumulating original set-by set data. However, it has been suggested recently that original operational (set-by-set) data provide more accurate CPUE estimate (Anon., 1994a). In addition, if daily (set by set) basis catch and effort data are used, daily basis ecological factors such as moon phase, temperature, and bycatch species can be fully utilized (Nishida, 1993c). Hence, fine-scale catch and effort data can provide more realistic and reliable estimation of abundance index.

3. Biological Parameters

Biological parameters such as growth rate, size-at-first maturity, or length-weight relationships change over time due to environmental influences, high levels of fishing pressure, and/or availability of food. Four recent studies of southern bluefin tuna by scientists from Australia's Commonwealth Scientific, Industrial and Research Organization (CSIRO) of Australia, found different biological parameters when comparing historical and recent data. Hearn (1994) suggests that the growth rate in the 1980s was much faster than in the 1960s. Davis (1994) shows that size (length)-at-first maturity (size at 50% of females being fully mature) in the 1990s is greater than the one in the 1960s. Anon. (1994a) suggests that length-weight relationships have changed over the last 30 years, that is, fish became leaner in recent years.

A few possible reasons for these changes are (1) changes of density of fish due to decrease of the population by fishing; (2) changes in the availability of food due to changes of the ecosystem (e.g., whale populations have been increasing in the southern bluefin tuna fishing grounds); and (3) changes of environments (e.g., inter-decadal climate changes) that affect marine ecosystems. Exact causes for the changes are not known and many of these are interlinked. These changes sometimes significantly affect results of the stock assessment and the projection of the stock abundance. In fact, Klaer et al. (1994) demonstrated discrepancies in projections of southern bluefin tuna populations between new and old biological information. Therefore, the life history strategy of tuna (biological parameters) must be closely monitored to detect statistically significant changes. Otherwise, results of stock assessment may be biased and jeopardize sustainable and responsible management of tuna fisheries.

4. *Cryptic Biomass*

The historical trend in average annual tuna longline CPUE shows a peak at the beginning fishing stage, then an exponential decrease, and finally a stable low level. At this low stage, even when there is continuous fishing pressure and/or there is other additional fishing pressure from purse seiners, further decrease is not seen (Nishida, 1991). This is observed in the average annual CPUE trend of longline fisheries data (Japan) for southern bluefin tuna (Figure 2a) and those for Taiwan, Japan, and Korea of Indian Ocean yellowfin tuna fishery (Figure 2b). Causes of these phenomenon have been questioned by tuna fisheries scientists. Recently, an interesting view was offered by Fonteneau (1995), that is, there is a cryptic biomass behind the estimated biomass. This cryptic biomass is thought to occur because of the tuna's dynamic vertical and horizontal migration, that is, longliners cannot catch all the tuna, especially when tuna migrates into deeper water or shallower water beyond the locations of the longline gear. In fact, Yamada (1991), Omori (1993), and Kawamura (1994) reported that echo sounders recorded images of tuna schools at waters depth of 500 m, 1000 m, 1500 m and 3200 m. These observations were confirmed by experienced skippers. This makes another uncertain factor in stock assessment.

5. *Spawner-Recruit Relationship*

In applying spawner-recruit models by Ricker (1954), Beverton and Holt (1957), or Shepherd (1982) for tuna, considerable noise around the estimated curves is quite often observed. Major causes of this noise are assumed to be oceanographic conditions during the time of spawning periods. This is because survival of eggs is critically affected by sea temperature and salinity, which are affected by extraordinary events such as abnormal timing or duration of monsoon, El Niño, etc. Therefore, if relatively unfavorable conditions continue for a long time during the spawning period, fewer eggs (recruitment) are expected to survive than under normal conditions and vice versa (Nasu, 1972). These factors need to be taken account in analyses when plotting spawner and recruitment data points. The usual spawner recruitment relationship averages all of the values and produces a curve that represents all data but assumes that environmental conditions are constant (Figure 3). If favorable and unfavorable environmental conditions are demonstrated to affect spawning and recruitment in tunas (and this remains to be validated

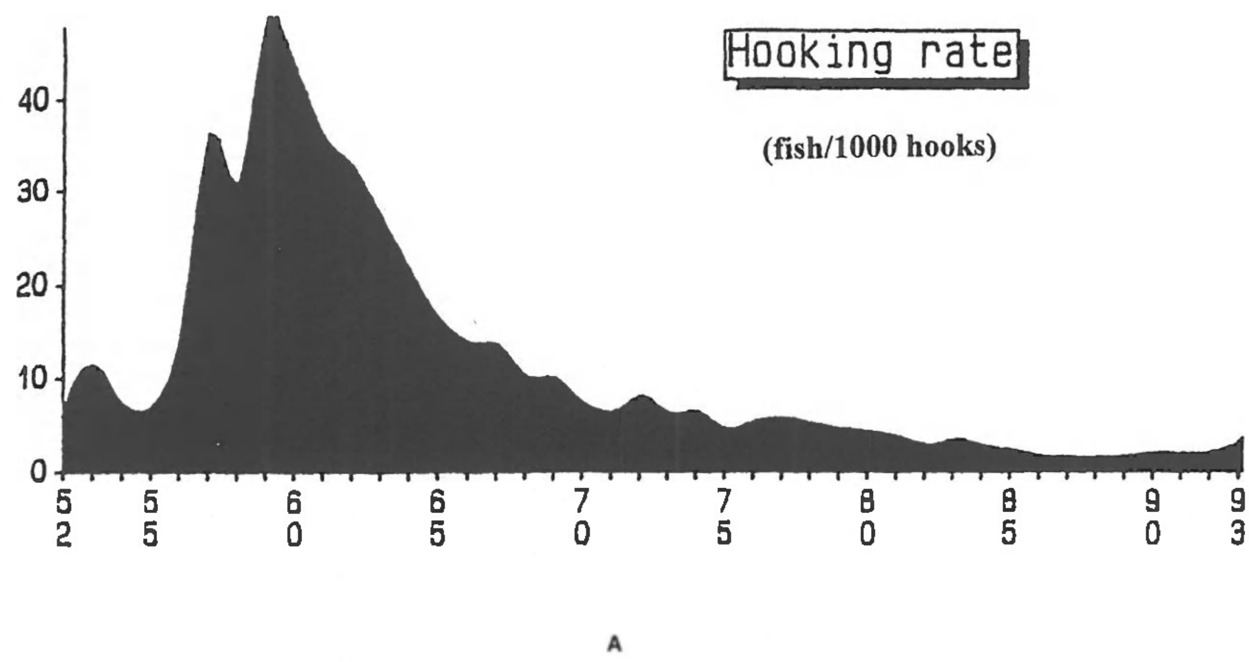

FIGURE 2. (a) Trend of annual Japanese longline CPUE of southern bluefin tuna (Anon., 1994a). (b) Trend of annual longline CPUE of yellowfin tuna in the Indian Ocean by China (Taiwan), Korea, and Japan (Nishida, 1992).

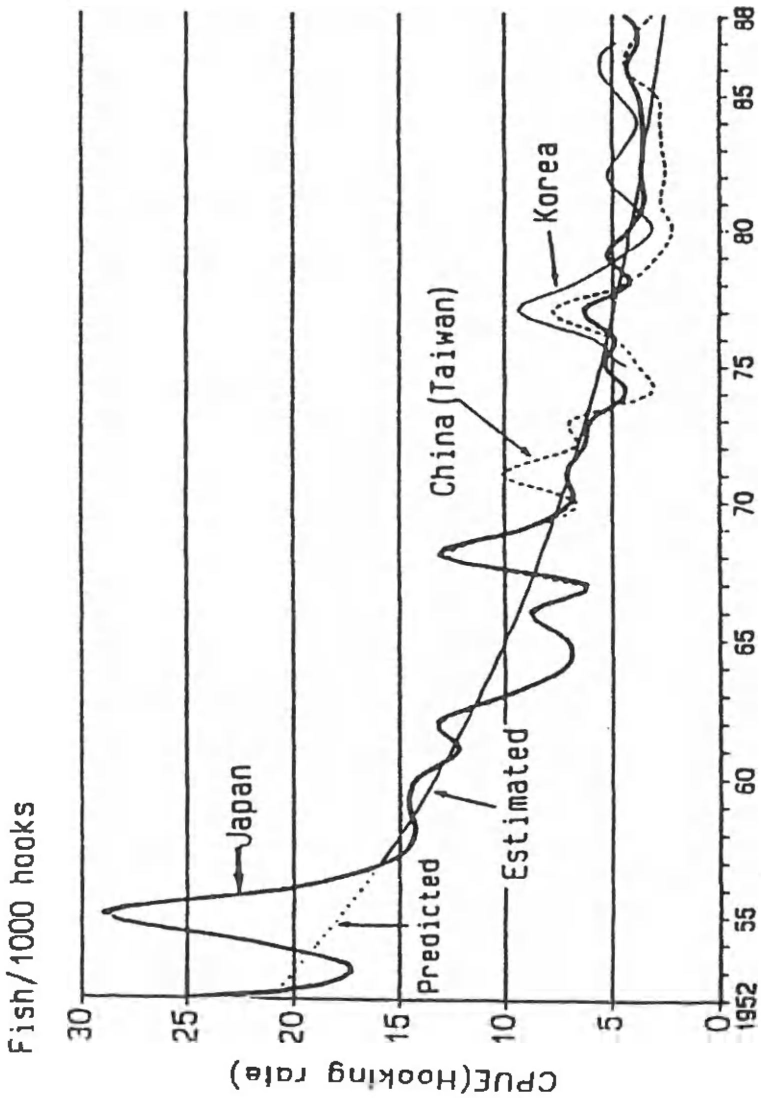
Fish/1000 hooks
CPUE(Hooking rate)
Japan
Predicted
Estimated
China (Taiwan)
Korea
30
25
20
15
10
5
0
1952
55
60
65
70
75
80
85
88

FIGURE 2B

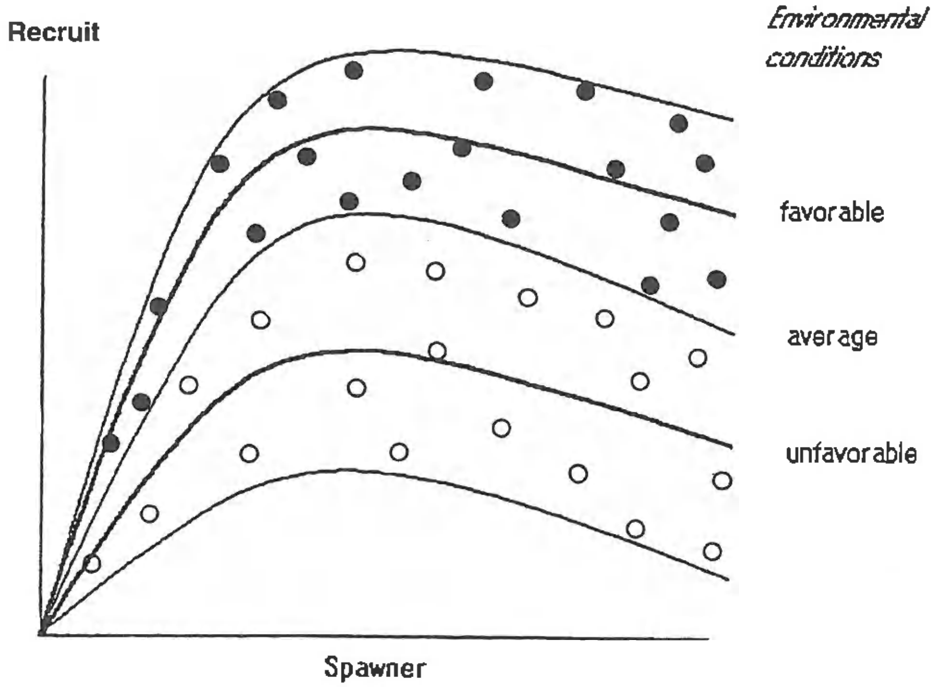

FIGURE 3. Potential effect of environmental conditions on estimates of spawner-recruitment relationships. (Source: Nishida).

empirically), then it may be more appropriate to construct spawner recruitment indicies based on prevailing environmental conditions. This approach would tend to provide more meaningful interpretation of the spawner recruitment relationships and contribute to more realistic assessments under prevailing environmental conditions.

C. SOME APPROACHES FOR IMPROVEMENT OF STOCK ASSESSMENT

1. Fisheries Independent Surveys

To overcome problems of uncertain quality of commercial fisheries data, fisheries independent surveys have been conducted by different methods. In the case of southern bluefin tuna, three major types of surveys have been implemented in order to obtain a more certain and reliable recruitment index than the index based on fisheries data alone. These survey types are experimental fishing, acoustic survey, and aerial survey, each of which is independent of commercial fisheries and conducted scientifically. These indices have been accumulated and they are likely more reliable indices of population levels of young southern bluefin tuna in comparison more to those estimated by the catch-based information. However, it has been reported that there are still different types of uncertainty in these survey data

(Anon., 1994b). Aerial survey, for example, exhibits uncertainty due to the cryptic biomass. Often the tuna schools are located deeper than 8 m from the surface, where spotters cannot see them. For this problem, light detection and ranging (LIDAR) and compact airborne spectrographic image (CASI) methods that can scan underwater objects at greater depths are being developed and tested. As a result of preliminarily tests, it was learned that CASI was not effective because it could not penetrate into the water and was like a passive video camera, while LIDAR provided positive signs, that is, it could be used to measure school size, fish size, and detect of southern bluefin tuna deeper than the spotter could see (Anon., 1995 and 1997).

2. *Robust Dynamic Models*

Nishida (1992 and 1993a) developed a robust stock assessment model by revising the stock fishery dynamic model by Tanaka (1980 and 1982). This robust model incorporates the dynamics between immature and adult tuna. Thus, it can specify characteristics of yellowfin tuna fisheries by gear type, that is, surface fisheries (purse seine and pole/line) mainly exploit immature fish, while the mid-water fisheries (longline) exploit mature tuna. This dynamic model based on immature and mature groups is an intermediate approach between production models (all ages pooled) and virtual population analysis (VPA: age specific approach). Hence, it is considered to be robust because the production model is too crude and VPA is too fine to handle uncertain data.

3. *ARTIFICIAL INTELLIGENCE (AI)*

Artificial Intelligence, such as expert systems, fuzzy logic, or neural network, are systems that can use a computer to process intellectual information based on specialist experience and knowledge that is expressed by simple information or rules (Hagiwara et al, 1993). AI is based on a methodology similar to the human thought process instead of equations and rigid logic. The merits of the use of these techniques in fisheries are that specialized descriptive knowledge from experts such as long-term fishermen, scientists, and managers can be utilized as input information. Especially for tuna fisheries, the information is rough and approximate, hence descriptive data such as 'high' catch, 'good' prediction, etc. might be just as adequate as the existing data to be used as input. Thus, these uncertain quality data are not appropriate to fit rigid and logical mathematical models like those used in engineering or physics or chemistry. As examples in Japan, these approaches have been applied to the cases of whale and skipjack fisheries data (Sakuramoto, 1991) and also to the forecasting of fishing and oceanographic conditions (Komatsu et al., 1994). Although the application of AI techniques to tuna has yet to be attempted, they are likely to be appropriate and feasible because of the various types of uncertainties and complexities that are involved. Therefore, the AI techniques are nominated as potentially effective to overcome some uncertainty problems in tuna stock assessments. These include limited and uncertain quantity of tuna fisheries data, unclear relationships between oceanographic conditions and tuna resources, uncertain biological parameters, and uncertain dynamics of tuna stocks.

4. *Spatial Analyses Using Geographical Information Systems (GIS)*

Because GIS is designed to produce spatial analyses, it is useful for managers or scientists interested in spatial dynamics of tuna distributions. With respect to responsible fisheries, stock evaluations by stock assessment scientists are still the key. Thus, the GIS can be utilized in an auxiliary manner to plan and manage fisheries based on the results of the stock assessment. For example, once quotas for catch or effort are determined, GIS can be used to allocate quota according to spatial circumstances such as distribution of bycatch species or size of tunas by area and season. Hence, spatially and temporally specific catch quota/effort can be effectively assigned by GIS analyses. In addition, studies on relationships between fisheries and ecosystems using GIS, such as forecasting for fishing and oceanographic conditions, have been increasing gradually. Such studies are expected to be expanded in the near future. Therefore, there is no doubt that GIS can become an important tool for managing sustainable and responsible tuna fisheries in the near future. Development and application of the GIS for fishery sciences has increased in recent years. There has been no specific GIS software for marine fisheries in the past. However, the Environmental Simulation Laboratory developed the marine GIS (ESL, 1997) as a first one of this kind, which can handle both fisheries and marine ecosystem information using a personal computer.

III. *MITIGATION OF BYCATCH*

The most critical issue for sustainable and responsible tuna fisheries is to mitigate bycatch. For example, if the United Nations adopts a ban on the catching of some of the bycatch species, then tuna fisheries with bycatch of such species will be suspended. In this article, 'bycatch' consists of (1) discards from fisheries, (2) incidental captures of protected and endangered species such as sea turtles, seabirds, some species of sharks, sea mammals, and billfishes, and (3) catch of immature tuna. Potential solutions and ongoing attempts to mitigate bycatch in tuna purse seine and longline fisheries are discussed.

A. *PURSE SEINE*

The primary bycatch species in the tuna purse seine fishery are undersized tunas and dolphins.

1. *Undersized Tuna*

Nishida (1991) reports that in the yellowfin tuna fisheries in the Indian Ocean, the catch of pole and line and troll fisheries consists of more than 40% of immature tuna (age 0 fish or fish less than 50 cm), while longline fisheries rarely catch small immature fish (Figure 4). It is known that in purse seine fisheries, size composition of catch is significantly different among free swimming, log-associated, and dolphin-associated schools. The results of these observations are summarized in Figure 4, that is, compositions of small immature (<50 cm) vs. large immature and adults (>50 cm)

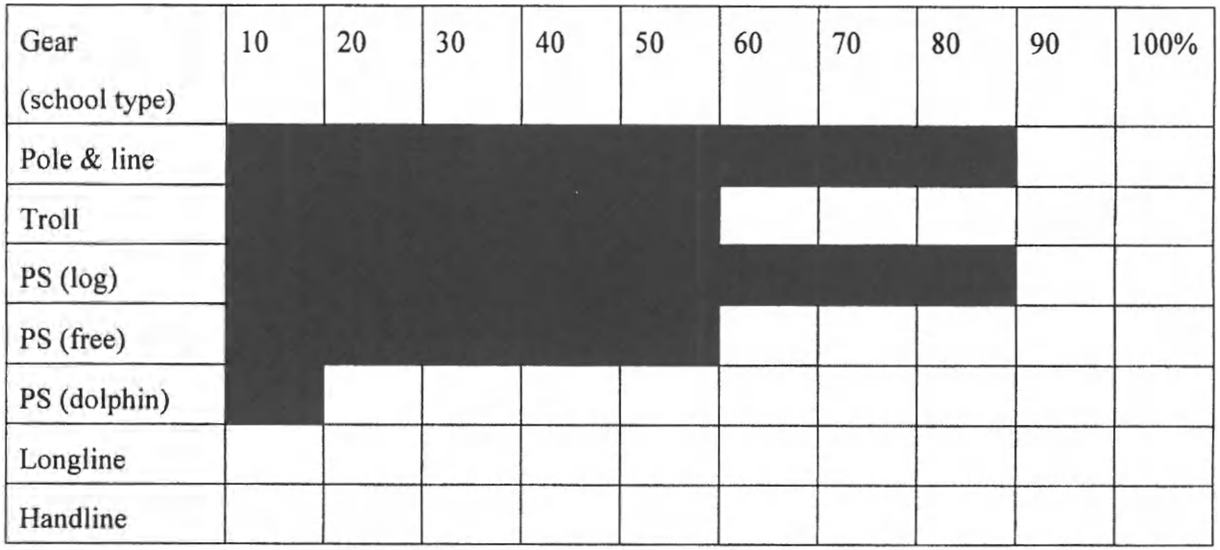

FIGURE 4. Average catch composition (in %) of immature yellowfin tuna (less than 50 cm) by gear type (PS: purse seine).

by gear type and school type. Changing fishing methods can help to avoid catching immature tuna, which is one of the management options, especially when the stock level becomes low. Similar results can be expected for other species, although gear types are slightly different.

2. Dolphin

In the eastern tropical Pacific Ocean, several million dolphins have been killed in the tuna purse seine fishery since 1959. Through combined efforts of the nations whose vessels participate in this fishery, annual dolphin mortality in the fishery was reduced from about 559,000 animals (at the peak in 1961) to about 15,000 animals in 1992 (Wade, 1993; Joseph, 1994). This large reduction is attributed primary to the widespread use of a dolphin-release practice called '*backing down*'. In addition, each licensed tuna boat is restricted to an annual dolphin kill quota by International America Tropical Tuna Commission (IATTC). If a skipper exceeds his limit, he must stop purse seining for the year, and the excess dolphin quota is deducted from his allotment for the next year. For non-member countries, unless dolphin-safe tuna fisheries are proven, tuna or tuna products cannot be exported to the IATTC member countries.

Although the Dolphin Safe Program in the eastern tropical Pacific still seeks greater reduction of dolphin kill (even to zero), it is considered to be the most effective mitigation program for tuna purse seine fisheries in the world (Carpenter, 1994). Data show that the dolphin kill rate in Sri Lanka, Philippines, Bay of Biscay is 7 to 17 times higher than bycatch in the eastern Pacific (Carpenter, 1994). To achieve responsible fisheries, other purse seine fisheries with a bycatch of dolphin could initiate a similar approach to that used in the eastern tropical Pacific to reduce dolphin kill.

B. LONGLINE

The longline is an effective fishing method to use to avoid catching small juvenile tuna in comparison to other gears. This is because the hooks of longliners are usually set midwater (50 to 300 m), where there are fewer immature tuna. Therefore, this gear targets mainly medium to large-size tuna. However, longliners harvest only a number of fish equivalent to a few percent of hooks. Thus, it is considered an ineffective fishing method. Because it is a passive fishing method, it harvests (selects) only those fish that are actively feeding. In these respects, this fishing method already satisfies some conditions of responsible fisheries. The problem is that longliners incidentally catch some endangered and protected species (seabirds, sea turtles, and some species of sharks/billfishes).

The impact of longline gear on these populations of bycatch species depends on how often they are captured, the total numbers captured relative to the population, and the mortality of discards (Hoey, 1992). In this section, bycatch of seabirds, turtles, and sharks is discussed and some ongoing and potential approaches to mitigate bycatches are explored.

1. Seabirds

The primary concern is over the accidental hooking and killing of the three highly endangered albatross species (Laysan, Black-footed, and Short-tail), which are at low population levels. Currently, Japanese fleets are utilizing tori poles and night operations to mitigate seabird bycatch.

a. *Tori Pole*

The tori pole (tori means bird in Japanese) was invented in Japan. It consists of a pole mounted on the vessel's port side from which a line is suspended approximately 150 m in length and to which ribbon type streamers are attached. This scares birds away from the freshly baited hooks while they are in surface waters. This device was originally tested among longliners operating on the southern bluefin tuna fishing grounds. Some seabird populations in the southern hemisphere, particularly albatrosses, are declining, and there is concern that longlining is a possible cause, due to the birds swallowing baited hooks and drowning. As a result of use of the tori pole, records of scientific observers of New Zealand, for example, show only 18 dead albatrosses during 262 sets (Murray et al., 1993). This is a dramatic reduction in seabirds deaths compared with the record between 1987 and 1990 indicating that one bird was killed in almost every longline set.

b. *Night Setting*

Tuna longlines can stretch 100 to 150 km, contain a few thousand hooks, and take 4 to 6 h to deploy. The critical period for bird mortality is between the time when the lines with baited hooks are thrown overboard and when they sink to beyond the reach of diving seabirds. Most diving birds are active during daytime. Thus, more birds are caught during daylight. Hence, allowing fishing operations to set their gear at night works particularly well and proves effective to avoid catching diving seabirds. If seabirds are caught and are still alive when brought on board, careful release must be practiced.

2. Sea Turtles and Sharks

In Japan, several methods are under development to mitigate bycatch of sea turtle by longliners. These include chemical lights, turtle safe hooks, etc. However, they are at the development stage and not yet in practical use. The only device used successfully in shrimp trawl fisheries is the turtle excluder device (TED). Such a mechanical exclusion device may not be possible to be deployed to due to the simple structure of longline gear.

Other methods to mitigate bycatches of turtles and/or sharks were suggested during the workshop on 'Bycatch in Fisheries and Their Impact on the Ecosystem' (Pitcher, 1994). These include: (1) attaching small acoustic devices (such as pingers) to the longline, which emit particular signals that turtles or sharks dislike, but have no effect on tuna, (2) put chemicals on baits (or use some types of baits) that do not affect tuna, but keep turtles or sharks away from baits, and (3) electrical charges that keep turtles and/or sharks away from hooks (maybe difficult because tuna might be also affected). The strategy might not be effective because it is reported that tuna are more sensitive to visual stimuli than chemical or acoustical stimuli (Kawamura, 1994). Still, a number of experiments on physiology and feeding behaviors of tuna, sharks, and turtles are needed to evaluate these methods. In addition, special care is required to quickly release turtles still alive after capture because they cannot survive very long out of the sea. If such care is not taken, turtle mortality may be high after released. Turtle biologists should develop methods and fishing crews should be trained in how to release turtles.

3. *Alteration of Gear*

Based on experimental longline fisheries in Hawaiian waters, Boggs (1992) and Hoey (1992) report that when bigeye tuna are targeted, eliminating shallow hooks of the longline gear could substantially reduce the quantity of bycatch without reducing fishing efficiency for bigeye tuna. Bycatch species in the bigeye tuna fisheries are spearfish (*Tetrapturus angustirostris*), striped marlin (*Tetrapturus audax*), other recreationally important billfishes, and sharks that inhabit shallow waters. It appears that this is a practical and effective approach to implement to reduce bycatch. Another suggestion is to shorten the length of the longline, so that bycatch of endangered and protected species can have more chances to survive after capture and release. This is because Boggs (1992) reports that more than 50% of tuna and bycatch species are alive if they are brought on board and released within 9 hours. If these two alternations are used and longlines are set during nights, the following benefits are expected: (1) greater survival of bycatch species, (2) better quality of tuna (higher commercial values) due to the shorter duration for hooked tuna under water, (3) less loss of tuna to predation by sharks and killer whales, and (4) safer and mentally better adjusted labor conditions through reduction in length of working hours. However, this suggestion might not be feasible because longliners prefer to keep traditional operations even if this method is effective to mitigate bycatch and is also a safer operational method.

IV. MANAGEMENT

Three potentially effective concepts for fisheries management to implement sustainable and responsible tuna fisheries are catch quotas for immature and adult tuna, time-area closures to mitigate bycatch, and the "fallow" concept.

A. CATCH QUOTA FOR IMMATURE AND ADULT TUNA

Biological, ecological, and behavioral characteristics between immature and adult tuna are quite different. Because immature and adult tuna are recruitment resources for each other, they are quantitatively interrelated. Hence, a single global catch quota is sometimes inappropriate. If, for example, a single global quota is applied and only immature tuna are harvested for many years, it causes recruitment overfishing. This leads to an unfavorable age structure in the population such as too few immature tuna or too few adult tuna. To avoid such bias in the population, a separate catch quota for immature and adult tuna is one of the options in fisheries management, especially when the stock levels of immature and/or adults are too low. Estimation methods for optimizing quota by immature and adult are complicated because of the necessity to consider factors such as stock status of immature and adult tuna, vulnerable size (age) by different gear, size (age)-at-maturity, lifespan, etc. Hence, this type of life stage-based management strategy needs to be carefully studied in advance of application.

B. AREA-TIME CLOSURE TO MITIGATE BYCATCH

Because the bycatch issue is the most serious problem with respect to developing responsible tuna fisheries at present, avoiding operations in waters with high-bycatch abundance is a feasible solution. If the situation is complex, GIS can be an effective tool to see detail and fine-scale waters by season to target fishing operation. For example, the successful harbor porpoise bycatch mitigation work in the Gulf of Maine, USA, is an example of use of this approach (Sheehan, 1994). One problem of the area-time closure was pointed out by Trumble (1992), however. If target species and bycatch of protected and endangered species are highly overlapped in a particular area and time, the effectiveness of area-time closure declines. Hence, it is necessary to carefully examine the most effective time-area closure strategies for the fisheries and species concerned. To find out more detailed vertical and horizontal migration paths of the endangered and protected species, different types of tagging experiments by conventional, ultrasonic pinger, and archival tags are useful tools.

C. FALLOW CONCEPT

Original idea of the 'fallow' concept is from agriculture, that is, to leave croplands uncultured for a year or more while they recover. This concept could be applied to tuna fisheries management by switching fishing effort from the waters where there is low stock abundance to the waters where there is a higher stock abundance. This concept could be especially useful for tuna because the global distributions of the five commercially important species do not overlap extensively both in horizontal and vertical dimensions. Thus, fishing can be concentrated more in waters where the higher stock level of species are distributed. During the fallow period, the stock status for all tuna species need to be carefully monitored. Then if the stock level of the weak species recovers and the stock level of some other species falls to a lower level, fishing effort could be switched to the areas where the recovered species occurs.

One example of how this might work is shown in Figure 5 (Nishida, 1988). The black squares represent regions of high bigeye CPUE and low yellowfin CPUE. The squares with X represent regions where there is high yellowfin CPUE and relatively low bigeye CPUE. Thus, if the goal is to harvest bigeye tuna with minimal bycatch of yellowfin, the fleet could be restricted to harvest in the black areas and leave the X areas fallow. Similarly, if the target is high yellowfin harvest with minimum bigeye catch, the fleet could be restricted to harvest in the X areas. Obviously, this sort of fallow management approach would depend on periodic and comprehensive monitoring of harvests. It also depends on full understanding of the seasonal behavior and migration of the various species of tunas. Use of GIS tools and techniques in close to real-time will facilitate this management approach.

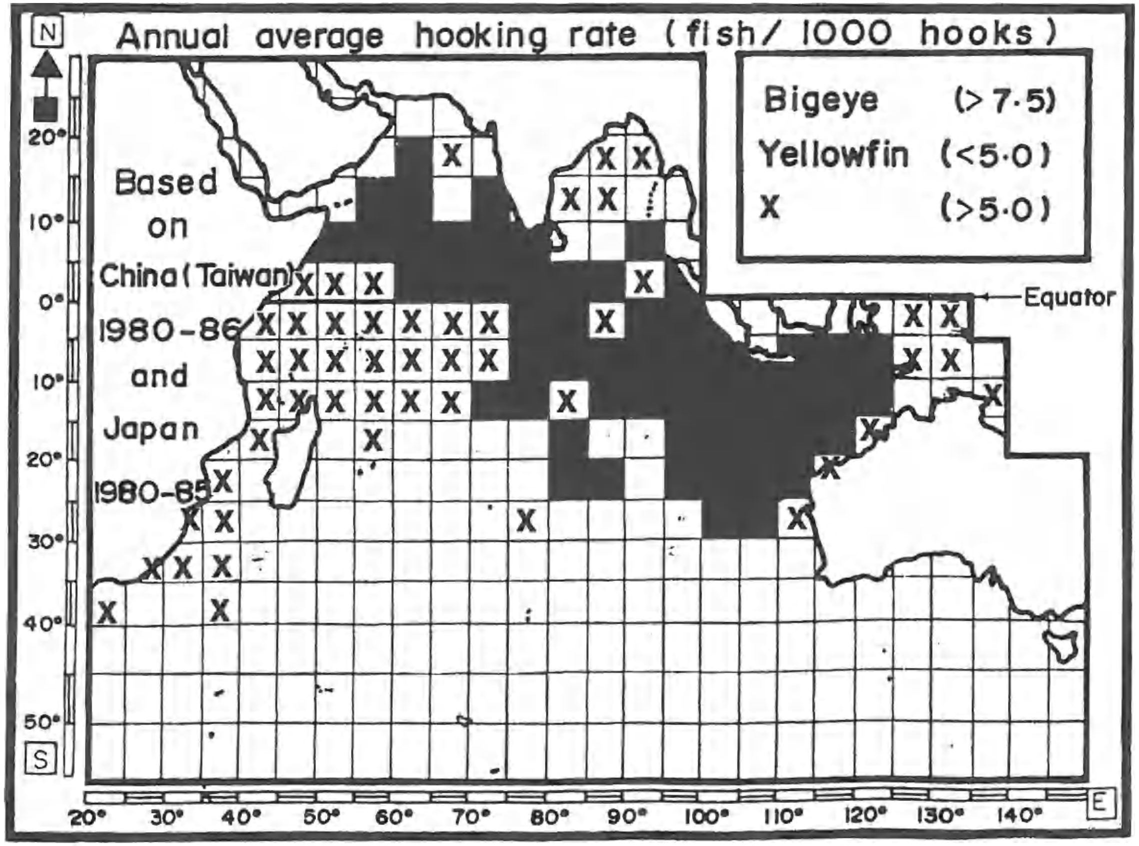

FIGURE 5. An example of the fallow concept. Unmarked 5 × 5 degrees areas are the fallow waters to conserve yellowfin tuna stock. Dark 5 × 5 degrees square areas are the preferable longline fishing grounds where there are less yellowfin and more bigeye tuna, so that bigeye (abundant stock) can be utilized, while the yellowfin (less abundant) stock is conserved during the fallow period (Nishita, 1988)..

When implementing the fallow concept, cooperation is essential from all nations fishing and, especially, from the fishing industry. Because tuna fisheries are driven by market incentives (Sakagawa et al., 1987), economic behavior of fishermen would normally cause them to fish on the highest CPUE of the target species to the detriment of bycatch of non-target species that may be at low levels. Fallow management approaches limit their behavior somewhat by restricting harvest to where CPUE of the target species is moderate to high but where non-target species are less abundant. This can be a way to conserve non-target species of tuna and to enhance prospects for recovery. Successful implementation of the concept requires acceptance by the fishermen and therefore the approach must be fully explained in advance and the long-run benefits demonstrated.

V. STOCK PROPAGATION

There are two general methods in stock propagation to rebuild tuna stocks: sea farming and aquaculture (stock enhancement). These approaches are considered effective methods in terms of sustainable and responsible fisheries. This is because tuna fishing nations need to be responsible for stock recovery especially for tuna species at low population levels such as southern and northern bluefin tuna. Of the two methods, sea farming for both species has been developed successfully and is practiced at present. Stock enhancement of tuna is currently one of the most interesting fields for tuna scientists, managers, and industries in Japan as well as other tuna fishing nations. In Japan, the initial research on stock enhancement started in 1949. Various fishery agencies, local fishery experimental stations, universities, and private enterprises have been working on tuna stock-enhancement programs. Despite these efforts over a long period, tuna enhancement programs are still at the preliminary and not practical stage because they require very high standard techniques. However, it is expected to succeed in the near future.

After tuna stock enhancement becomes practical, five potential problems need to be addressed to meet the standard for sustainable and responsible tuna fisheries, that is, (1) tuna fisheries management needs to consider the global stock status that is based on both fisheries and stock enhancement, (2) if stock enhancement is too successful, carrying capacity problems need to be addressed in order to balance ecosystem, (3) international joint research is needed to monitor released tuna, (4) fundamental international research is also needed to monitor genetic diversity of tuna, and (5) pollution of marine environments due to aquaculture propagation programs must be avoided through proper management. This last point also applies to the ongoing tuna sea farming.

VI. CONCLUSION

Tuna have been an important protein resource for both developed and developing countries for many years. For the Twenty-First Century, the food security issue can be expected to continue. Demand for tuna production is expected to rise because of increased population and greater incomes for consumption. Therefore, tuna fisheries must continue to play a role in food supply, even if the amount of tuna production is low in comparison to agricultural products. Because tuna, as well as other fish, are renewable resources, tuna resources can be utilized forever if they are properly managed. For human beings to utilize tuna resources forever, tuna need to be conserved and sustained. As discussed in this article, if tuna fisheries fail various conditions stated in the 'Code of Conduct for Responsible Fisheries', tuna fisheries might be suspended someday and will end. Even though there are some difficulties for implementing the Code, tuna fisheries scientists, managers, and industries must increase efforts to diminish these problems. If they are successful and succeed in the future, the world opinion will fully support tuna fisheries. It is the authors' intent and hope that the concepts and approaches discussed in this article can be utilized to mitigate problems in implementing sustainable and responsible tuna fisheries.

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