REVIEW AND RESEARCH PLAN ON THE STOCK STRUCTURE OF YELLOWFIN TUNA (*THUNNUS ALBACARES*) AND BIGEYE TUNA (*THUNNUS OBESUS*) IN THE INDIAN OCEAN

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Introduction

Concrete knowledge of fish stock structure is essential for resource management. Without it there is no basis on which to estimate fundamental aspects of a stock such as its maximum sustainable yield (MSY). For highly migratory pelagic species like tunas and salmons in particular, detailed information on population structure is a prerequisite for successful international fisheries management.

The Indian Ocean Tuna Commission (IOTC) was established in 1996, in order to strengthen the management role of the previous body, the Indo-Pacific Tuna Management and Development Programme (IPTP). One of the most essential tasks for the IOTC is therefore to elucidate the stock structure as the basic information needed for management. Because yellowfin and bigeye tuna are the most important tuna species in the Indian Ocean, this paper reviews the stock structure of these two species and describes research plans based on the review.

In past studies of the stock structure of tuna and tuna-like species, various data were used to examine heterogeneity within each species, i.e., DNA, morphometrics, tag-recapture data, parasites and fishery data. Of these, tagging is the most effective approach because it provides direct proof of movement, and hence the boundaries, of homogeneous stocks. Morphometric, DNA and parasitological approaches are secondary choice methods because they can identify stocks almost directly. Fishery data is the least appealing method because the data are not intentionally collected for the stock study, hence certain assumptions need to be made in the analysis.

Review and discussion

Yellowfin tuna

Yellowfin tuna is a commercially important species and attention has recently been paid to the necessity of managing this species (IPTP, 1990) in the Indian Ocean. The reasons for this were: (a) the continuously decreasing trend of the catch rates of large yellowfin caught by the industrial longline fisheries since the start of the exploitation in 1952, (b) the recent heavy exploitation by the industrial purse-seine fisheries in the western Indian Ocean, and (c) the lack of research activity in the Indian Ocean compared with the other oceans.

In the Indian Ocean, stock structure studies have been conducted both locally (Kurogane, 1960; BOBP, 1988; Cayré and Ramcharrun, 1990) and globally (Kurogane and Hiyama, 1958; Morita and Koto, 1970; Yano, 1991; Nishida, 1992). In addition, Ward *et al.* (1997) studied the worldwide stock structure in three oceans. In that study, samples from Sri Lanka were analysed In our paper, we will review those studies covering the entire Indian Ocean.

Kurogane and Hiyama (1958) analysed morphometric data on yellowfin collected from six different locations (Map 1) in the Indian Ocean and concluded that there were three stocks, one in the western Indian Ocean and two in the eastern Indian Ocean, one in the Andaman Sea area of the central-eastern region and the other in the Lesser Sunda area of the far-eastern region. Morita and Koto (1960) analysed the Japanese longline fishery data (1961-65) and concluded that there were two stocks, western and eastern, with the boundary at approximately longitude 100°E. Yano (1991) reported results of tagging experiments conducted by the R/V *Nippon-maru*, chartered by the Japan Marine Fishery Resources Research Center (JAMARC) from 1980-90 and covering a large area in the Indian Ocean (Map 2). Despite substantial tagging activities by the *Nippon-maru* in the past years, only two cases of long-distance movements from the central Indian Ocean to the western region were found (Map 2). In addition, 3 more long-distance tags were recovered indicating movements from Seychelles to Maldives. These 5 cases confirm exchange of fish between the central and western Indian Ocean. Other long-distance tag recoveries were reported by IPTP (1990) and Cayré and Ramcharrun (1990).

Although a two- or three-stock structure appears plausible, no past papers on stock assessment used this information, but assumed a single stock (Miyabe and Koido, 1986; Marsac and Hallier, 1987; Wang and Tanaka, 1988; Miyabe and Suzuki, 1991). The major reason for using the single-stock hypothesis is probably that the heterogeneous stock hypothesis is still not strongly confirmed by tagging experiments and other direct methods. Another practical reason might be that the single-stock hypothesis makes the analysis simpler.

Studies and experiences in other oceans indicate that yellowfin stock units are formed longitudinally and they intermingle in adjacent waters with variations by season, year and environmental conditions (Kamimura and Honma, 1963; Royce, 1964).

These studies can be summarized as follows, using Map 3 (after Nishida, 1991):

1. Kurogane and Hiyama's (1958) morphometric study implies a 3-stock structure, |(2-3)|(4)|(5)|, with strong intermingling trends in sub-area 4.
2. Morita and Koto's (1971) study found a 2-stock structure, *i.e.* |(1-2-3-4)|(5-6)|, with possible mixing of the two stocks in waters adjacent to both.

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3. JAMARC's tagging experiments proved exchange of fish between sub-area 2 and 3.
4. The IPTP tagging experiments proved movement from Maldives to Sri Lanka, *i.e*., movements from sub-area 3 to 4 in the stock boundary waters are confirmed.

On the basis of this information, we conclude that the yellowfin stock consists of two major and two minor stocks, depicted in Map 4 (Nishida, 1991). The two major stocks are the western and eastern stocks. The core western stock is likely located approximately in and around sub-areas 2 and 3 (longitude 40°-80°E), extending to part of sub-area 4, while the core eastern stock, located approximately in and around sub-areas 4 and 5 (longitude 80°-120°E), extends to both neighbouring sub-areas 3 and 6. The two minor stocks are the far western and the far eastern stocks, which are located in and around sub-areas 1 and 6, respectively. The stock in sub-area 6 might be a part of the western Pacific stock, which also extends to adjacent waters (sub-area 5) and intermingles with the eastern stock of the Indian Ocean.

Bigeye tuna

The only concrete study of the stock structure of bigeye tuna in the Indian Ocean is from Kume *et al.* (1971). It is based on the distribution, size composition and sexual maturity of the fish, and suggests a single stock, for the following reasons: (a) sexually-active individuals predominate in equatorial waters, indicating that fish of equatorial and southern waters intermingle, (b) it is not possible to detect a change in pattern in an east-west direction, although this does not necessarily imply that the stock is homogeneous, (c) morphometric comparisons between east and west have shown some differences, but have not been conclusive, (d) high hook rates observed off South Africa indicate mixing of fish of the Indian and Atlantic Oceans, and (e) mixing of Pacific and Indian Ocean populations appears to be slight.

In relation to point (d) above, very recently Chow *et al.* (1998, in press) studied the mixing ratios of bigeye tuna between the Atlantic and Indian Oceans around South Africa using DNA analyses. They suggested that the two stocks are heterogeneous, that gene flow between the Atlantic and Indian Oceans is restricted in one direction, and that fish from two distinct stocks are mixing around South Africa.

In addition, the worldwide studies of bigeye tuna stock structure by Alvarado-Bremer (1998) conclude that there are two major stocks, the Atlantic stock and the Indian-Pacific stock.

As in case of yellowfin tuna, past studies (Miyabe and Koido, 1985; Marsac and Hallier, 1986; Miyabe, 1988; Miyabe and Suzuki, 1991; Hsu and Chang, 1994; Okamoto and Miyabe, 1996) assumed a single bigeye stock in their stock assessments. As for yellowfin, the major reason for using the single-stock hypothesis is probably that the heterogeneous stock hypothesis is still not strongly confirmed by tagging experiments and other direct methods. Again, another practical reason might be that the single-stock hypothesis makes the analysis simpler.

Research plan

Hypotheses

Based on the review of past work, we proposed the following hypotheses and research plans.

Yellowfin tuna

The population of yellowfin tuna in the Indian Ocean consists of two major stocks, eastern and western, with three areas of intermingling: far western, off Southern Africa (Atlantic and western stock), central (eastern and western stock), and far eastern, off Java (eastern and Pacific stock).

Bigeye tuna

The population of bigeye tuna in the Indian Ocean consists of a single stock, with an area of intermingling between the Indian and Atlantic Oceans off South Africa.

The primary approach to use in confirming this is based on DNA analyses. Other approaches which may be considered when time and budget are available are analyses of conventional tag recapture data and fisheries data and archival tagging experiments.

Genetic polymorphism (DNA analyses)

Studying stock structure using genetic analyses of microsamples of tissue is a method recognized in recent years by Ward *et al*. (1998), Chow and Ushiama (1995), Alvarado-Bremer *et al*. (1995; 1998) and many others as easy (in terms of sampling), efficient, and accurate. We therefore plan to use this genetic polymorphism technique as the primary method for studying the stock structure of yellowfin and bigeye tuna in the Indian Ocean.

To conduct this study, we need to collect muscle samples from different locations, as indicated in Map 5. The study area is divided into eastern, central, and western regions, and each of these three regions is further divided into northern, central, and southern regions, for a total of nine regions.

We will provide the small containers for the 80 samples required from each location, and will need the cooperation of local fisheries research officers to collect the samples. The method for collecting samples is shown in Figure 1. Samples from juvenile fish (age 0-1) are preferable, but those from larger fish (age 2 or older) are also acceptable as long as the minimum sample number of 80 is satisfied.

Other approaches

Although the primary approach is genetic analysis, other methods described in this section will be used if time and budget permit.

Analyses of tag-recapture data

The R/V *Nippon-maru*, a purse seiner chartered by JAMARC, has been investigating tuna-fishing grounds in the Indian Ocean since 1980. The primary task is to explore good fishing grounds for skipjack, yellowfin, and bigeye tuna and examine the effectiveness of FADs. Conventional tagging experiments were also conducted as an ancillary survey. Some 500 fish have been tagged and released each year, approximately 80% skipjack, 10% yellowfin, and 10% bigeye) (Miyamoto, JAMARC, *pers. comm*.). Initial analyses of yellowfin tag recapture data were conducted by Yano (1990) (Map 2), but no further analyses have been carried out. The recapture data for these species have been collected and compiled by NRIFSF, and it would be desirable to update the analyses for yellowfin and conduct the first analyses for bigeye.

Analyses of fisheries data

Studying stock structure from fisheries data is the least appealing method because the data are not intentionally collected for stock studies. However, studies by Morita and Koto (1960), Kume *et al.* (1971), and Nishida (1991) indicate that long-term fisheries data could provide a rough picture of the stock structure, since the results of these and other studies and of tagging experiments mostly matched in the case of yellowfin. Therefore, fisheries data can be an alternative method if the long-term data are used. Since these studies, more data have been accumulated (there are now 44 years of data for the Japanese longline fisheries), so it would be worthwhile to attempt a similar study. If the analytical method used by Nishida (1991) is applied, different longitudinal divisions (areas to be analysed) need to be examined to see if consistent results can be obtained for all the cases (Sakagawa, NMFS, *pers. comm*.) (Map 3).

Archival tagging experiments

Archival tagging experiments are the best method for studying stock structure because they provide direct evidence of fish movements. In recent years, this type of tag has been used primarily with temperate tunas, *i.e.,* northern bluefin tuna in both Pacific and Atlantic Oceans, and also southern bluefin tuna. However, the tags are extremely expensive. Therefore, it will be not possible to conduct this type of experiment in the Indian Ocean unless extensive funds are available or until the price of the tags becomes much lower.

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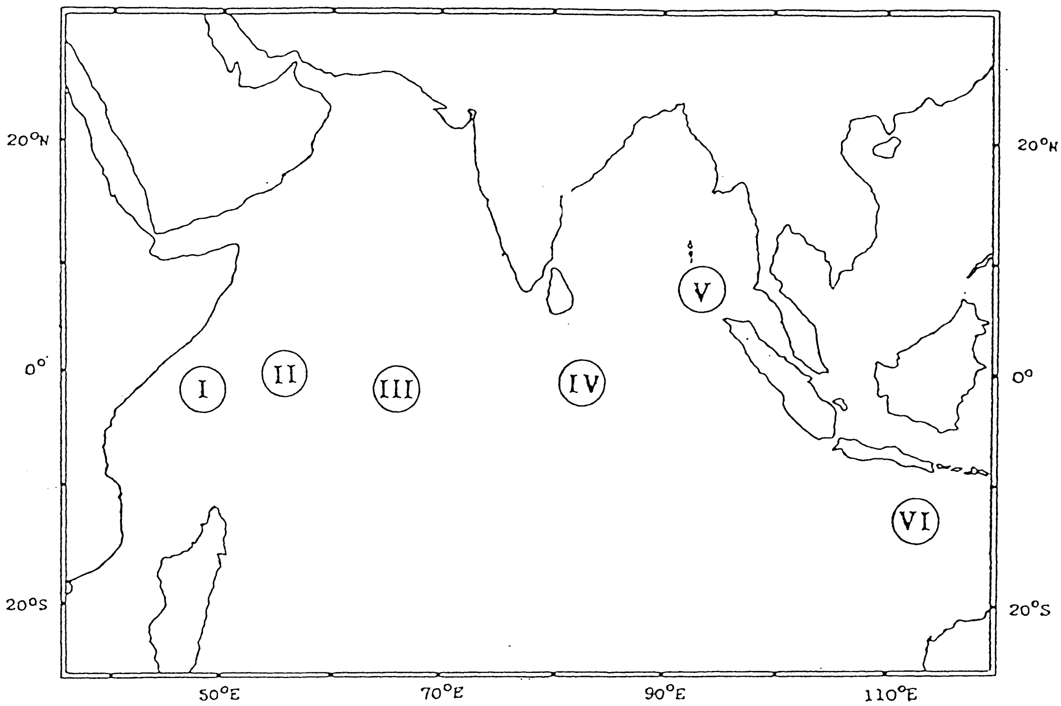
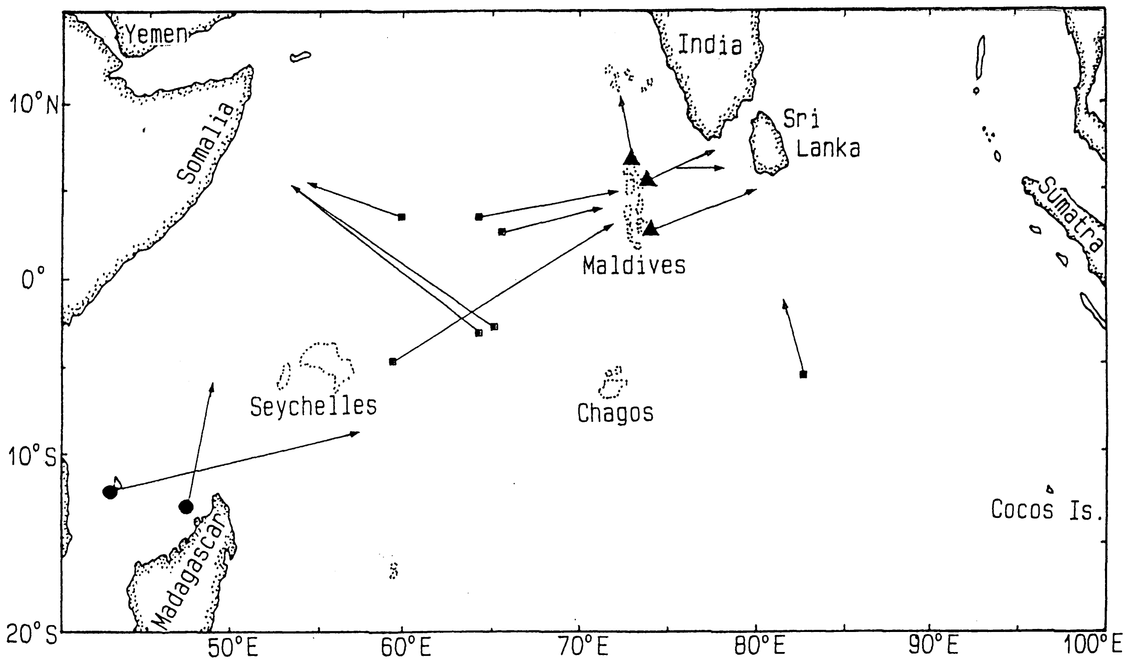
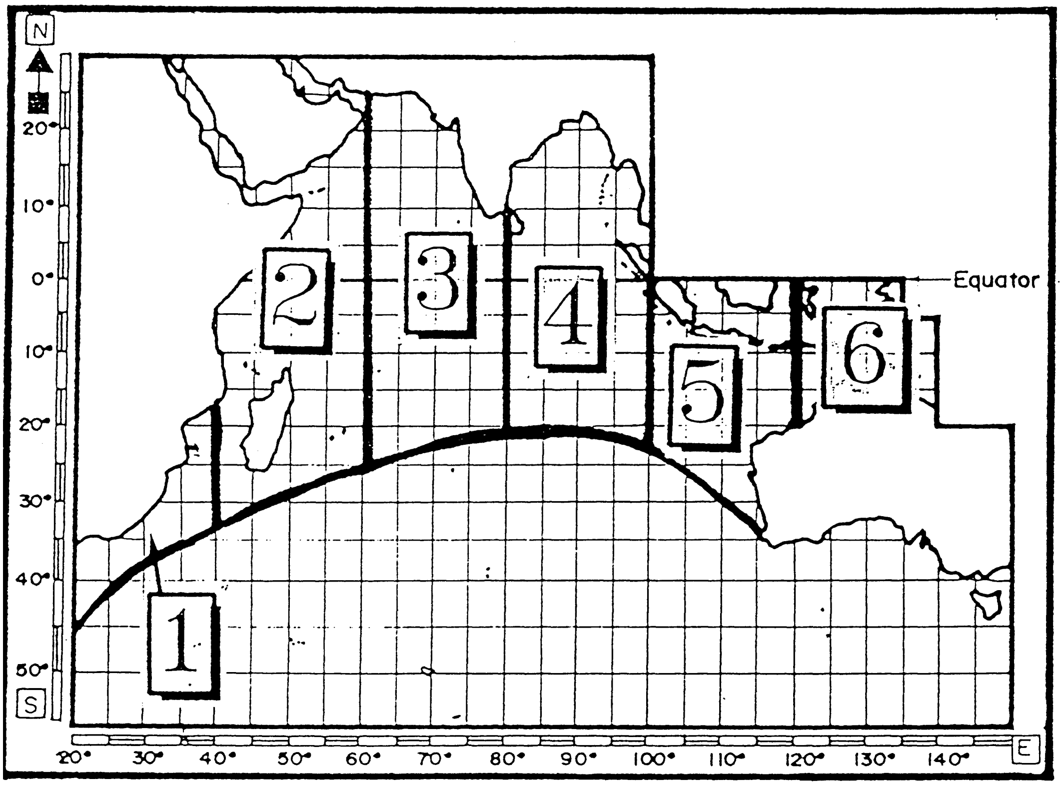


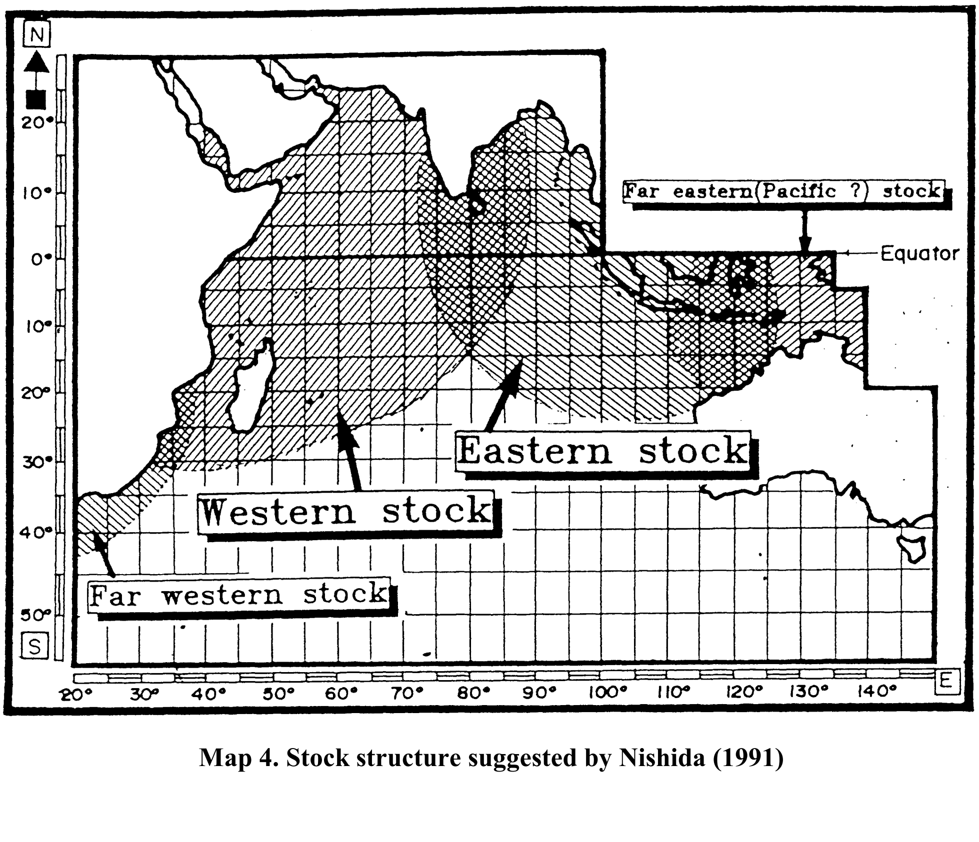
Map 1. Six sampling areas in the Indian Ocean selected for the morphometric study by Kurogane and Hiyama (1958)



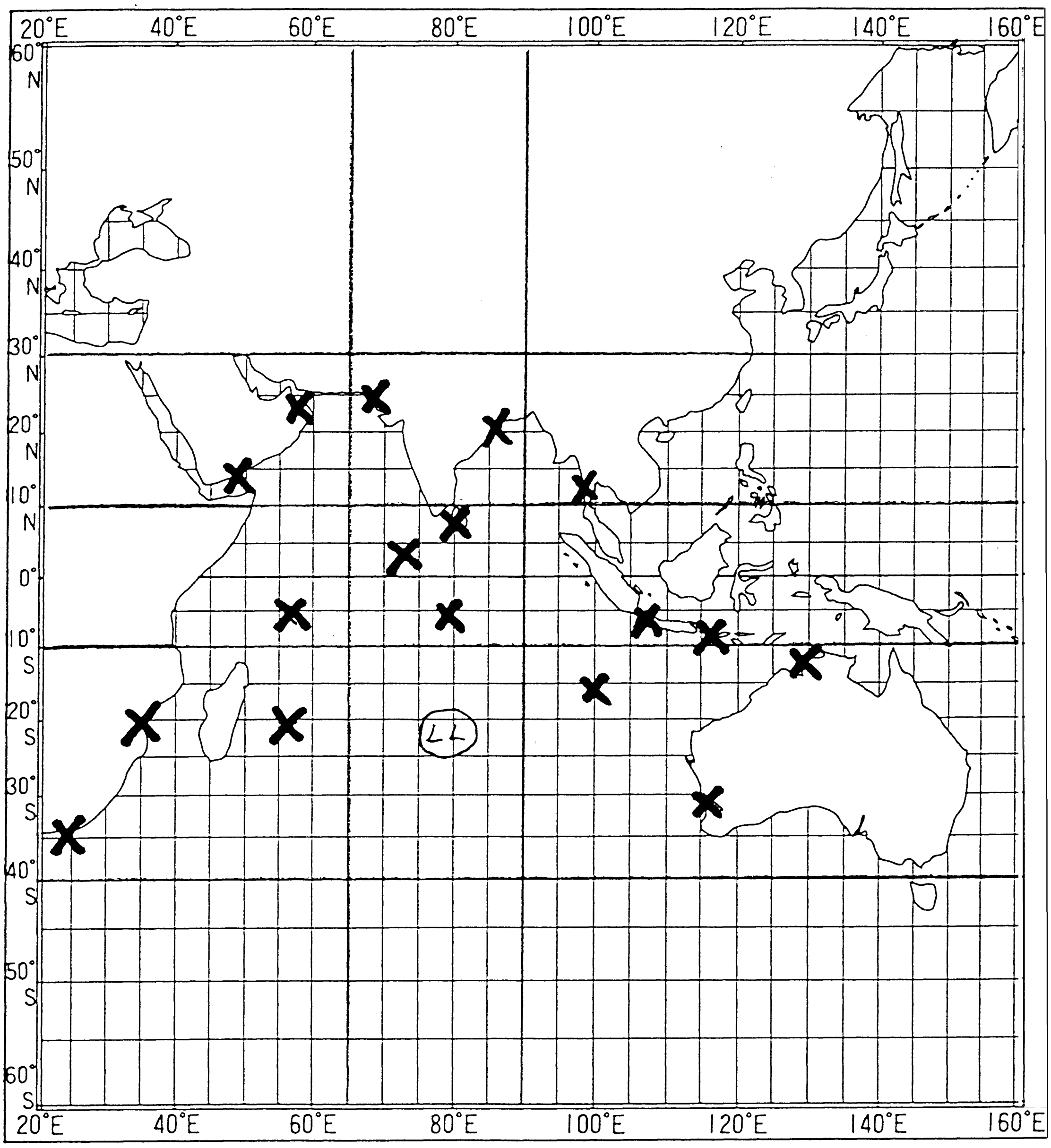
Map 2. Major results of past tagging experiments (summary of long-distance recoveries).



Map 3. Areas defined for the stock structure study by Nishida (1991)



Map 4. Stock structure suggested by Nishida (1991)



Map 5. Possible sampling locations (final locations will be determined after cooperation is confirmed by the research officers in these areas)

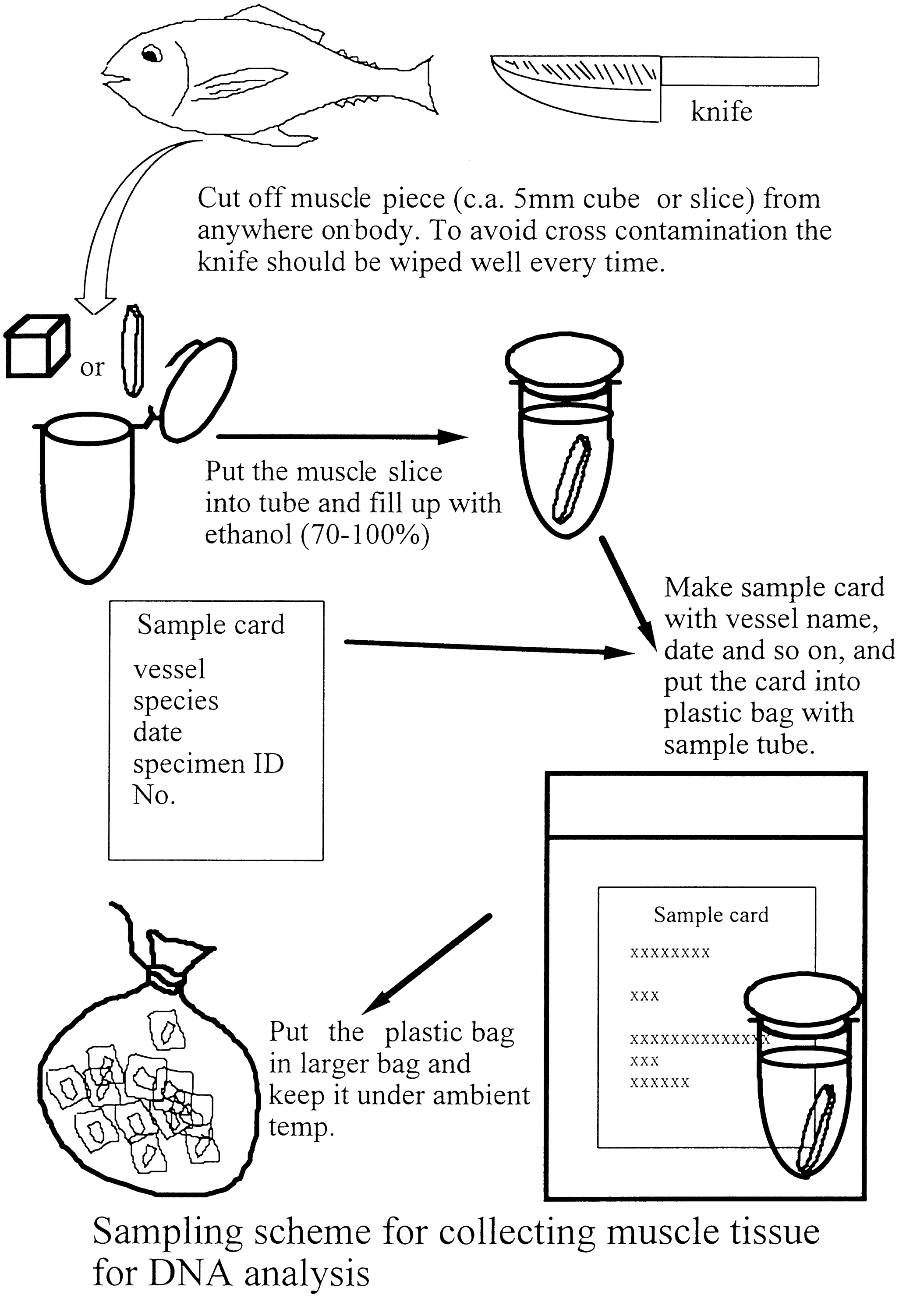


Figure 1. Sampling methods