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The Revised Management Procedure of the International Whaling Commission: managing the harvest of mixed stocks of baleen whales

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ABSTRACT

In the early 1980s, the International Whaling Commission established a pause in commercial whaling. One reason cited for this was that scientific uncertainty precluded calculation of safe catch limits using available methods. After eight years of development, in 1994 the IWC adopted (but has not yet implemented) the Revised Management Procedure (RMP) for baleen whales. The RMP is based on the principle of explicitly taking scientific uncertainty into account. The single-stock Catch Limit Algorithm at the core of the RMP has been extensively tested through simulation to ensure robustness to a wide range of uncertainty about: population dynamics, errors in catch and abundance data, etc. However, in real applications, management of multiple stocks is necessary. Here the RMP takes account of uncertainty in knowledge of stock structure and mixing through the spatial spreading of catches. The latter is achieved through evaluating the performance of the RMP in simulated applications to a range of plausible stock structure hypotheses specified to cover the range of uncertainty. A key feature is that catch limits are set for so-called *Small Areas*, defined as areas known to contain only one stock or, if multiple stocks are present, those stocks mix so that catches can only be taken in proportion to abundance. The greater the uncertainty in stock structure, the more *Small Areas* are defined.

INTRODUCTION

Some twenty years ago, the International Whaling Commission (IWC) voted to implement a pause in commercial whaling. At that time, the rationale put forward by those in favour was that there was insufficient knowledge about whale population abundance and dynamics to establish safe catch limits in accordance with the 'New Management Procedure' (NMP) being used to manage whaling at that time. As part of the decision to establish zero catch limits, the IWC agreed to undertake a 'Comprehensive Assessment' of whale stocks, after which catch limits other than zero might be set (Donovan 2002).

The Comprehensive Assessment was defined as "an in-depth evaluation of the status of all whale stocks in the light of management objectives and procedures … that … would include the examination of current stock sizes, recent population trends, carrying capacity and productivity" (Donovan 1989). A key part of this was to examine alternative management regimes, given the problems encountered with implementing the NMP. Accordingly, the IWC Scientific Committee began the development of what turned out to be a major advance in the management of a natural resource.

The approach was based on the explicit recognition of scientific uncertainty and an appreciation of what data were available and were likely to become available. The IWC Scientific Committee used computer simulation to provide a framework for the rigorous testing of a number of candidate single-stock management procedures[1]. A policy decision was made to develop a 'generic' approach to management for application to a single stock of any baleen whale species being harvested on its feeding grounds, rather than a specific approach whereby a procedure was developed for each species/stock being exploited.

The RMP was developed on the understanding that a robust and effective management procedure must have the following attributes: explicitly stated and prioritised objectives; be based on realistic data requirements; incorporate uncertainty explicitly; include a feedback mechanism; and be rigorously tested.

The management objectives of the RMP were determined by the IWC to be:

(1) To ensure an acceptable risk that a stock not be depleted below 54% of its carrying capacity, at a probability level set to allow stocks to recover to 72% of carrying capacity, so that the risk of extinction of the stock is not seriously increased by exploitation;

(2) To ensure the highest possible continuing yield from the stock;

(3) To ensure stability of catch limits, desirable for the orderly development of the whaling industry.

Clearly, these objectives cannot all be maximised so the RMP had to find an appropriate balance; the IWC gave highest priority to the first objective.

After eight years of development involving five candidate procedures, the resulting single-stock *Catch Limit Algorithm* (*CLA*) of the RMP was deemed robust to all plausible uncertainties (IWC, 1992; Cooke, 1995).

However, in real applications, the IWC must be able to manage multiple stocks of a species in an ocean. To take account of uncertainty in knowledge of stock structure and the mixing of stocks, the RMP spreads catches over space (and time) by setting catch limits for areas that are small relative to the area inhabited by a stock. To determine how big these so-called *Small Areas* need to be, further simulation tests specific to a particular species in a particular area and subject to a particular harvesting regime are necessary. These are specified to cover the plausible range of uncertainty in stock structure and are known as *Implementation Simulation Trials*.

The final scientific product (the RMP) comprises the single stock *CLA*, rules about how to deal with multi-stock situations, rules about data requirements, a phase-out rule for situations in which data are not available within the required timeframe, and a rule for adjusting catches if the sex ratio of the catches is heavily skewed towards females (IWC, 1999).

THE SINGLE STOCK CATCH LIMIT ALGORITHM

Learning from the difficulties encountered in trying to implement the NMP, the IWC Scientific Committee agreed that any revised management procedure must be based on data that were (or could easily be) available in terms of quality and quantity. This limited the available data to:

(1) Any historical and all ongoing catches;

(2) Absolute abundance estimates available prior to management and periodically thereafter;

(3) Catch-related relative abundance data, i.e. catch per unit of effort (CPUE) data.

In the later stages of CLA development, CPUE data were abandoned because of difficulties in their interpretation (Donovan 1989). The abundance data are obtained from surveys that are independent of whaling operations; detailed guidelines for such surveys and subsequent data analysis have been determined.

During CLA development, candidate procedures were subjected to a set of rigorous 'robustness' trials designed to judge their performance in relation to a wide range of uncertainties. These examined violations of assumptions commonly made in whale stock assessments and the calculation of catch limits. The main robustness trials conducted are given in Table 1.

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[1] The advantage of a management procedure is that it covers all aspects of management in accordance with pre-specified objectives, including data and analysis requirements, a specified way of calculating catch limits, and rules for all expected situations.

Table 1.

Examples of the robustness trials with which candidate single stock management procedures were challenged.

- Different population dynamics models and associated assumptions
- Different starting population levels, ranging from 5% to 99% of the 'initial' population size
- Different MSY levels, ranging from 40% to 80%
- Different MSY rates, ranging from 1% to 7% (including changes over time)
- Various levels of uncertainty and biases in abundance estimates
- Changes in carrying capacity (including reduction by half)
- Errors in historic catch records (including underestimation by half)
- Catastrophes (irregular episodic events when the population is halved)
- Various frequencies of surveys

To evaluate performance, and to allow comparison between candidate procedures, a set of summary statistics was specified in relation to the three management objectives. For the 100 simulations of each trial, these were the lower 5%-ile, median and upper 95%-ile of: total catch after 100 years of management; final stock size after 100 years; lowest stock size during the 100 years; average annual catch over the final 10 years (a surrogate for the realised long term yield). To these was added a measure of the inter-annual variability in catches.

Eventually, one *CLA* was chosen. It incorporates a very simple population dynamics model (a discrete time version of the Pella-Tomlinson model) that does not require prior estimates of biological parameters (Cooke, 1995; IWC, 1999); there is no attempt to mimic reality in the underlying model used for management.

The population dynamics model is fitted to the catch and abundance data using Bayesian methods in which information from new data is deliberately down-weighted to limit the speed at which the management procedure responds to feedback. The catch control law sets a catch limit of zero if the estimated population depletion is less than 54% of carrying capacity, and a positive catch limit based on estimated stock productivity otherwise. Details are given in IWC (1999).

MANAGEMENT OF WHALING ON MORE THAN ONE STOCK

The single-stock CLA at the core of the RMP was developed specifically to set safe catch limits for single stocks of baleen whales for which there is no uncertainty about the identity of the stock. In practice, this situation will rarely, if ever, arise. Whaling operations can be expected typically to take animals from more than one stock, the relationships among which will generally not be well defined. A management area could include a single stock in entirety, but it is more likely to include part of one stock, either alone or together with parts of one or more other stocks.

The importance of uncertainty in stock structure is readily illustrated by considering the simple case in which it is not known how many stocks inhabit an area in which whaling consistently occurs in only one part of the area. Suppose that there are two stocks, one that inhabits the whole area and one only occurs in the exploited area. If whaling is managed as if there were only one stock, the *CLA* will calculate the catch limit based on total estimated abundance in the whole area. The stock that only occurs in the area covered by whaling operations will be harvested more heavily and is likely to be overexploited. This simple case exemplifies the uncertainty facing management of a typical coastal whaling operation.

It is clear that the single stock *CLA* alone is insufficient for the safe management of whaling. 'Multi-stock rules' are required to dictate its application in a variety of cases in which stock structure is not straightforward, or is uncertain, or both. The starting point for such rules can be taken from the simple example above. In the absence of knowledge about whether there are one or two stocks in the area, the safe solution is to relate the catch to the number of whales in the area of operation. In other words, robust management in the face of uncertainty in stock structure must be based on areas that are smaller than they would be if knowledge were certain. This fundamental principle is at the heart of the multi-stock rules in the RMP.

Multi-stock robustness trials

The RMP's multi-stock rules were developed through multi-stock robustness trials. These were designed to mimic management of whale stocks subject to three types of whaling: a typical coastal whaling operation; a typical pelagic (open ocean) operation; and a mixture of the two.

The coastal whaling trials examined the simple case in which whales can be found (and surveyed to obtain estimates of absolute abundance) over a much wider area than that from which they are taken by a coastal whaling operation. The pelagic whaling trials were based on Southern Hemisphere minke whaling. They examined situations in which the true identity of stocks in the Antarctic Ocean matched a variety of stock structure hypotheses. A third set of trials was designed to mimic mixed coastal and pelagic minke whaling operations in the North Atlantic.

There was early indication from the results of the multi-stock robustness trials that, for effective conservation of stocks, catch limits had to be set for areas that were much smaller than previously used by the IWC for management. This fundamental principle is enshrined in the RMP through the general rule that within an ocean basin, catch limits should be set for *Small Areas*, defined as areas small enough to contain whales from only one biological stock, or to be such that if whales from more than one biological stock were present, catching operations would be unable to harvest them in proportions different to their relative abundance in the area.

Multi-stock rules (RMP variants)

The basic way to apply the RMP is to use the CLA to set catch limits for a species in each *Small Area*. There are two additional variants of this, known as *Catch-cascading* and *Catch-capping* (IWC, 1999), summarised below.

Catch-cascading is where a number of *Small Areas* are combined and the catch limit calculated by the CLA for this *Combination Area* is distributed to *Small Areas* in proportion to estimated abundance. This variant would be appropriate where there is biological information suggesting two or more *Small Areas* could be combined and results of trials indicated adequate performance of *Catch-cascading* compared to application of catch limits to *Small Areas*. It is a way of increasing the size of areas for which catch limits are set without compromising the principle of setting catch limits for areas that are sufficiently small to ensure adequate conservation.

Catch-capping is for cases where the catch limit calculated for a combination of *Small Areas* is less than the sum of the catch limits calculated for each *Small Area* separately. In the application of this variant, the catch limits calculated for each *Small Area* are reduced proportionally. *Catch-capping* is an additional safety net at a scale larger than *Small Areas* for cases where this is deemed appropriate.

Taken together, these multi-stock rules, or RMP variants, provide a framework within which the *CLA* is used for the safe management of whaling. They deal with uncertainty in stock structure and the related issue of whale movement patterns by spreading catches over space (and potentially time). In any particular case, the relative performance of a range of RMP variants in a series of *Implementation Simulation Trials* (see below) is used to determine which variant (i.e. *Catch-cascading, Catch-capping* or neither) is appropriate, using the risk- and catch-related performance statistics specified above.

Implementation Simulation Trials

Implementation Simulation Trials are case-specific extensions of multi-stock robustness trials. For a species in a region of interest, they lead to the specification of *Small Areas* and provide the information needed to select among RMP variants where there may be multiple stocks mixing in areas where catches (or surveys) may take place. Case-specific *Implementation Simulation Trials* are needed because the generic multi-stock robustness trials were designed to come up with general multi-stock rules (RMP variants) and tested only a limited range of uncertainties in stock structure. Constructing generic multi-stock trials to cover all feasible situations would in any case be impossible.

The first step in developing a set of *Implementation Simulation Trials* is to identify a range of plausible alternative hypotheses about stock structure based on the available data. This means identifying the number of breeding stocks, and postulating whether it is necessary to include other potential breeding stocks because of lack of data in an important area. It also involves considering whether there is a need to subdivide breeding stocks into 'sub-stocks', for example because of a tendency for groups of animals to show preferences to feeding areas where catches (or surveys) may take place.

Each putative breeding stock, and how it interacts with other breeding stocks (i.e. its patterns of migration, dispersal and mixing on feeding grounds), must be specified in time and space. The geographical aspect of this is done by dividing the ocean basin into sub-areas, which should have the same properties as the *Small Areas* described above. Breeding stocks typically occupy a subset of sub-areas, some of which they will share with other breeding stocks.

Taken together, the various combinations of number of breeding stocks and how they interact with each other form the set of alternative stock structure hypotheses. The critical point here is that all these hypotheses should be plausible given the available data; there is clearly no point in testing an implausible hypothesis. However, some hypotheses may be more plausible than others, and the judgement of relative plausibility may vary widely from one scientist to another. A general solution to the way in which relative plausibility is taken into account in using the results of *Implementation Simulation Trials* to determine which RMP variant to apply in any particular case has not been resolved by the IWC Scientific Committee. Currently, this is achieved through the balance of opinion in the Committee.

Implementation Simulation Trials may also test hypotheses about uncertainties other than stock structure, e.g. catch histories, level of bycatch, biological parameters. This is especially important if there is concern that the case-specific uncertainties may not have been fully explored in robustness trials during the development of the *CLA*.

Having identified the hypotheses, the next step is to develop and fit the models that represent them. The basis of these operating models, like the multi-stock robustness trials, is a set of equations providing the simplest description of the dynamics of the stocks that is compatible with the available data and will allow an appropriate RMP variant to be chosen. It is important to stress that the aim is not to model the dynamics of a stock through time and space in as complex a way as possible. Data are used either to fix model structure or parameters, or to represent uncertainties in other parameters to which the models are fitted. Two key components of the models are the catch mixing matrices and the sightings mixing matrices, which quantify the movement and mixing patterns of the putative breeding stocks as they affect harvesting and abundance surveys, respectively.

Because *Implementation Simulation Trials* are testing the performance of the RMP in managing whaling in the future it is also necessary to specify a number of operational factors. These include when and where future surveys will take place, and whether there are any areas or time periods in which whaling will not be allowed. The final step is to specify the alternative RMP variants to be tested.

CASE STUDY: COMMON MINKE WHALES IN THE NORTH PACIFIC

Developing *Implementation Simulation Trials* common minke whales (*Balaenoptera acutorostrata*) in the North Pacific has been a long and complicated task. One of the main reasons for this was the need to reflect the spatio-temporal factors involved in scenarios with whaling occurring on migration; the RMP was designed for the simpler situation of whaling on the feeding grounds. Other reasons included the need to incorporate bycatch in fishing gear in catch histories and future removals, the increase in data (if not interpretation of those data) on stock structure of this species in this area, and debate in the IWC Scientific Committee about the level of complexity (including what comprises a 'plausible' stock structure hypothesis) needed in *Implementation Simulation Trials* (IWC, 2003).

The uncertainty in stock structure makes the case of common minke whales in the North Pacific a good illustration of how the RMP is used to manage whaling on multiple stocks.

The area considered is the western North Pacific; there are few data from the eastern North Pacific and no intention of whaling there. Figure 1 shows the area and the 18 sub-areas chosen for structuring the *Implementation Simulation Trials*. The delineation of these sub-areas reflects both knowledge and uncertainty in stock structure. There is a known stock in the Sea of Japan (the J stock occurring mainly in sub-areas 1, 5, 6 and 10), individuals of which can be differentiated from other stocks using genetic analysis. This stock mixes with one or more other stocks occurring to the north and east (sub-areas 7W, 7E, 11, 12SW in some months). Four scenarios (A-D) were chosen to capture the uncertainty in stock structure to the north and east of Japan (IWC, 2003; 2004).

Scenario A involves three stocks (J, O & W). It assumes certain migration routes to feeding grounds for the O stock. Temporal mixing of O and J stock occurs in some sub-areas and the W-stock occurs sporadically in sub-area 9 (see Figure 2).

Scenario B is a limiting case of Scenario A with no W stock.

Scenario C involves four stocks (J, O_W, O_E and W). The preferred hypothesis is for boundaries between stocks O_W and O_E at 147°E and between stocks O_E and W at 158°E with no mixing. Other alternatives were also modelled (see Figure 3).

Scenario D involves three stocks (J, O, W) with the O and W stocks mixing across the 147°-162°E region. The O stock dominates in the west and the W stock dominates in the east (see Figure 4).

These scenarios were modelled via catch-mixing matrices that specifies the fraction of each stock that occurs in each sub-area each month by age and sex (juveniles, males age 10+ and females 10+).

The RMP variants considered in the *Implementation Simulation Trials* and the sub-areas from which catches are taken when a *Small Area* consists of more than one sub-area were:

(1) *Small Areas* equal sub-areas. For this option, the *Small Areas* for which catch limits are set are 7W, 7E, 8W, 8E, 9W, 9E, 11, 12SW and 12NE;

(2) 7+8, 9, 11 and 12 are *Small Areas* and catches are taken from sub-areas 7W, 9W, 11 and 12SW;

(3) 7+8+11+12 and 9 are *Small Areas* and catches are taken from sub-areas 11 and 9W;

(4) 7W, 7E+8+12, 9 and 11 are *Small Areas* and catches are taken from sub-areas 7W, 9W, 11 and 12SW;

(5) 7+8+11+12 is a *Combination Area* within which catches are cascaded to sub-areas, and 9 is a *Small Area*;

(6) as (3), except that the catches from the 7+8+11+12 *Small Area* are taken from sub-areas 7W and 11 using *Catch-cascading* across those two sub-areas.

The full set of *Implementation Simulation Trials*, for assumed MSY rates of 1% and 4%, included a large number of sensitivity tests investigating, *inter alia*, depletion of the J stock ranging from 15%K to 70%K, various levels of mixing and intrusion, differing assumptions about bycatches in Japanese and Korean fishing gear, and survey bias.

The results of the *Implementation Simulation Trials* showed that, regardless of which stock structure hypotheses were considered plausible (scenarios A-D), variants 1 and 5 were always acceptable on risk-related performance statistics. Variant 5 performed better on catch-related statistics. All variants performed acceptably on risk-related performance under scenarios A and B. There was disagreement in the IWC Scientific Committee on the relative plausibility of the different stock structure scenarios. Some members believed that only scenario A was plausible and that variant 6 was preferable, given the catch related statistics and the whaling operations envisaged. Most members believed that scenarios C and D were also plausible and, therefore, that variant 5 was preferable (IWC, 2004).

CONCLUDING REMARKS

The development of the RMP represents a major step forward in the management of natural resources, particularly in the way it takes scientific uncertainty explicitly into account. However, its application in the real world of multiple stocks is more problematic. To a large extent, this reflects difficulties in interpreting data on stock structure. Whilst there are agreed ways of analysing survey data to arrive at an abundance estimate, there are no agreed ways of analysing the several sources of data on stocks (e.g. see Donovan 1991). Attention has recently focussed on genetic data (IWC, 2003) but there is genuine scientific disagreement on their interpretation with respect to present stock structure and management. In practice, most available methods for analysing genetic data have not been tested via simulation to any extent, particularly in a management context. The IWC Scientific Committee has recently established a research programme to do this (IWC 2004). The North Pacific case study described above represents one of the most complex scenarios for management (with whaling almost exclusively on a migratory corridor). The example illustrates that there are several issues that have not been fully resolved. Perhaps the most important surrounds the question of 'plausibility': what is the minimum level of evidence required to consider a hypothesis 'plausible'; how should competing 'plausible' hypotheses be ranked; and what process should be employed to recommend the most appropriate RMP variant?

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Figure 1. Sub-areas used in Implementation Simulation Trials for common minke whales in the western North Pacific.

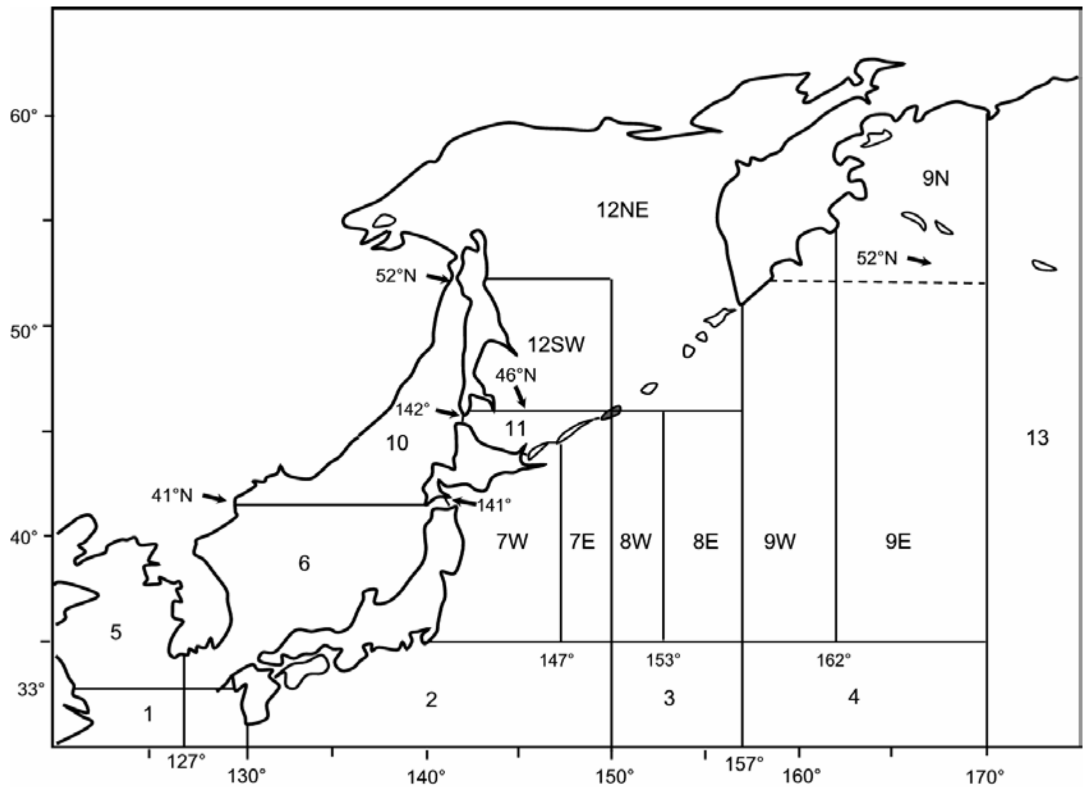

Figure 2. Schematic illustration of North Pacific common minke whale stock structure Scenario A

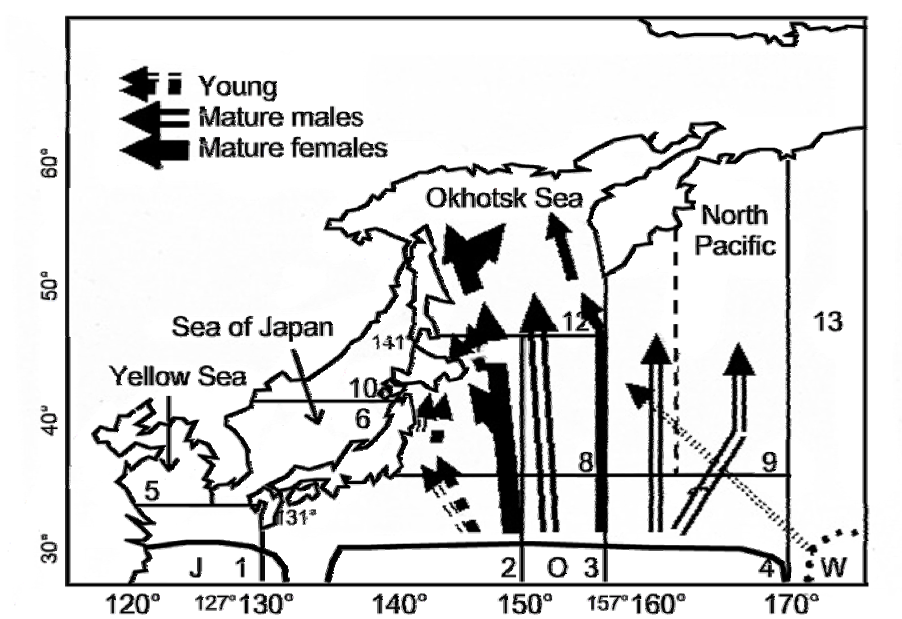

Figure 3. Schematic illustration of North Pacific common minke whale stock structure Scenario C

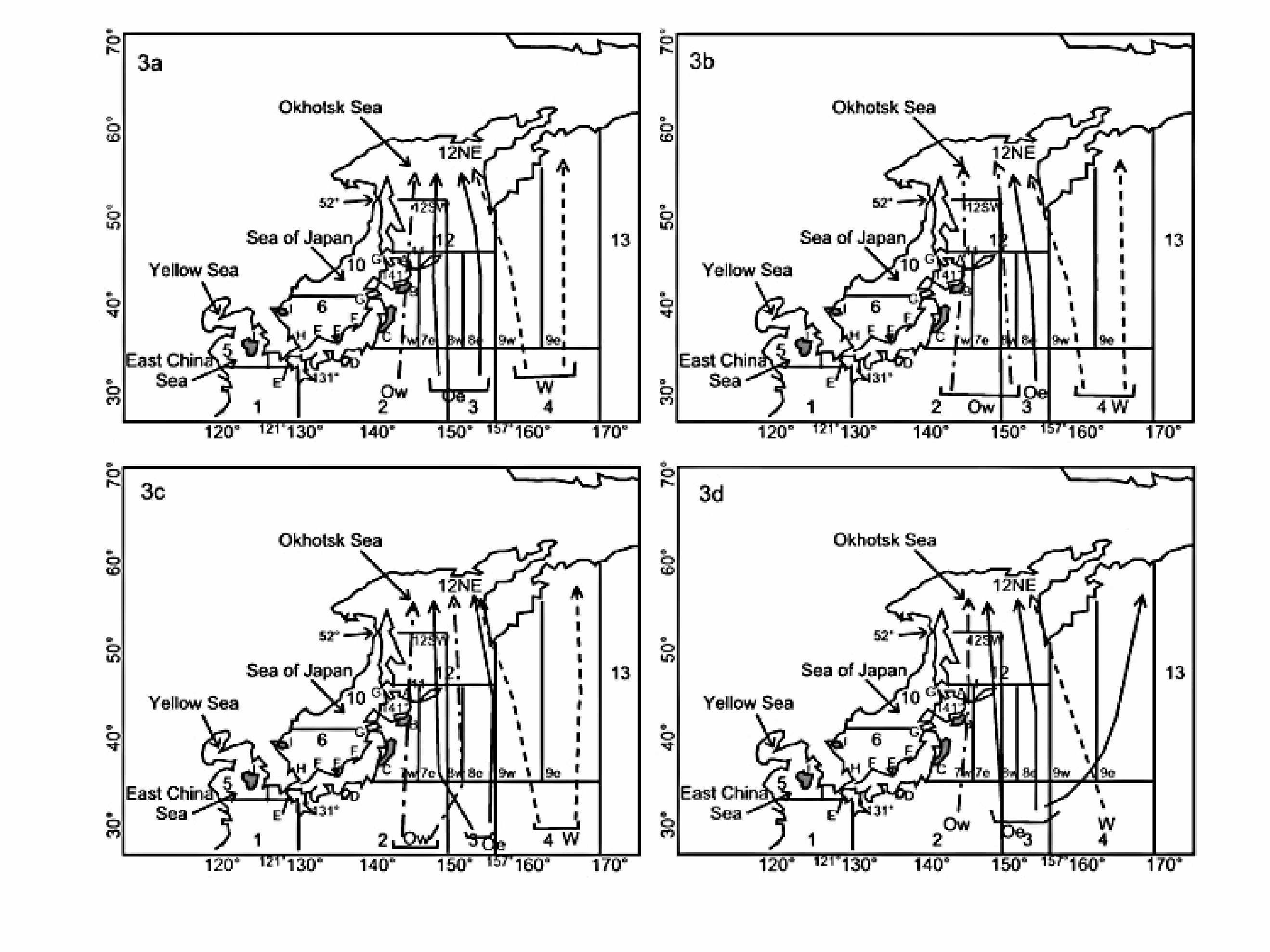

Figure 4. Schematic illustration of North Pacific common minke whale stock structure Scenario D