FAO Fisheries Circular No. 1023 **FIMF/C1023 (En)**

ISSN 0429-9329

STOCK ASSESSMENT APPROACH FOR THE NAPOLEON FISH, *CHEILINUS UNDULATUS*, IN INDONESIA

A tool for quota-setting for data-poor fisheries under CITES Appendix II Non-Detriment Finding requirements

Copies of FAO publications can be requested from:
Sales and Marketing Group
Communications Division
FAO
Viale delle Terme di Caracalla
00153 Rome, Italy
E-mail: publications-sales@fao.org
Fax: (+39) 06 57053360

***Cover photograph*:** Napoleon fish, C*heilinus undulatus.* Courtesy of P.L. Colin of the Coral Reef Research Foundation.

FAO Fisheries Circular No. 1023 FIMF/C1023 (En)

STOCK ASSESSMENT APPROACH FOR THE NAPOLEON FISH, *CHEILINUS UNDULATUS*, IN INDONESIA

A tool for quota-setting for data-poor fisheries under CITES Appendix II Non-Detriment Finding requirements

by
Yvonne Sadovy
Department of Ecology and Biodiversity
University of Hong Kong
China, Hong Kong Special Administrative Region

André E. Punt
School of Aquatic and Fishery Sciences
University of Washington
Seattle, WA, United States of America

William Cheung
Fisheries Centre
University of British Columbia
Vancouver, Canada

Marcelo Vasconcellos
Fisheries Management and Conservation Service
Fisheries and Aquaculture Department
Food and Agriculture Organization of the United Nations
Rome, Italy

Sasanti Suharti
Research Center for Oceanography
Indonesian Institute of Sciences
Jakarta, Indonesia

Bruce D. Mapstone
Antarctic Climate and Ecosystems Cooperative Research Centre
Hobart, Tasmania, Australia

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS
Rome, 2007

ISBN 978-92-5-1055775-9

This CD-ROM includes a Microsoft® EXCEL® file with a Visual Basic macro that runs the model.

SYSTEM REQUIREMENTS:

- PC with Pentium® I or higher processors
- MS Windows® 95® or Windows® NT Workstation with 3.51 Service Pack 5 or later
- Microsoft® EXCEL® 97 or higher versions

PREPARATION OF THIS DOCUMENT

The Napoleon fish (humphead wrasse) was listed in the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) Appendix II in 2004. Following listing, different efforts were directed towards assessing the stock of Napoleon fish in Indonesia (the centre of the species distribution and main exporter to the live reef food fish trade) and developing an approach to assist range States in addressing CITES non-detriment finding requirements. This document consolidates the results of research projects funded by CITES, The World Conservation Union (IUCN) and the Food and Agriculture Organization of the United Nations (FAO) (GCP/INT/987/JPN "CITES and Commercially-exploited Aquatic Species, Including the Evaluation of Listing Proposals"). Various experts and government officials working with coral reef fish fisheries in the Indo-Pacific region provided valuable inputs for the preparation of this document. The authors thank in particular the members of the Effects of Line Fishing (ELF) project team, Australia, for allowing them to make use of the age, length and maturity data for Napoleon fish collected as part of the ELF project, and Pat Colin (Coral Reef Research Foundation) for advice on abundance estimation. Dr Michel Kulbicki (Institut de recherche pour le développement, École pratique des hautes études, France), and Mr Leban Gisawa, of the National Fisheries Authority, Papua New Guinea, are thanked for providing and organizing data on length frequency and population counts. Dr Eric Williams (Southeast Fisheries Science Center, United States of America) is thanked for providing stock recruitment data of Vermillion snapper. Faustina Ida Hardjanti (Departemen Kehutanan, Indonesia) and Ilham (Departemen kelautan dan Perikanan, Indonesia), Dr Suharsono (Indonesian Institute of Sciences, Indonesia) and Robert Glazer (Florida Fish and Wildlife Conservation Commission) are also thanked for contributions to this project. Dr Gavin Begg (Australian Fisheries Management Authority) and Dr Richard Little (Commonwealth Scientific and Industrial Research Organisation, Marine and Atmospheric Research, Australia) are thanked for their comments on a draft of this report. The approach described in this Fisheries Circular is implemented in an Microsoft EXCEL spreadsheet which is included in the CD-ROM provided with this publication.

Sadovy, Y; Punt, A.E.; Cheung, W.; Vasconcellos, M.; Suharti, S.; Mapstone, B.D. 2007. *Stock assessment approach for the Napoleon fish*, Cheilinus undulatus, *in Indonesia. A tool for quota-setting for data-poor fisheries under CITES Appendix II Non-Detriment Finding requirements*. FAO Fisheries Circular. No. 1023. Rome, FAO. 2007. 71pp. Contains a CD-ROM.

ABSTRACT

A stock assessment approach for the Napoleon fish (humphead wrasse), *Cheilinus undulatus*, is presented as a tool for determining sustainable catch levels of the species. The model was developed primarily for application in Indonesia and in collaboration with the Research Center for Oceanography, Indonesian Institute of Sciences (LIPI). The model can be adapted for estimating sustainable catch levels in other countries, if suitable estimates of reef area and fish densities are available. The approach is composed of a population model and a method for estimating stock density based on underwater visual surveys, allows for the representation of "grow out" of net-caged animals, a significant part of the trade, includes the ability to account for uncertainty in most of the parameters of the model, and can compute a sustainable catch (and its associated uncertainty) corresponding to a user-specified level of fishing mortality. The resultant model is implemented using Microsoft EXCEL and Visual Basic, with a graphical user interface for easy use (the EXCEL spreadsheet is included in the CD-Rom provided with this Fisheries Circular). Sustainable fishing mortality rates for the species in Indonesia can be estimated based on commonly used biological reference points (e.g. F_{MSY}; $F_{20\%}$). Results of sensitivity tests indicated that the relationship between stock and recruitment remains the major uncertainty affecting the estimation of sustainable fishing rates. Preliminary estimates of export quotas for Indonesia are provided taking into account the official statistics on the volume of domestic catches and estimated illegal and unreported exports. Estimated export quotas were highly sensitive to the estimated habitat area suitable for the species, which highlights the need for more accurate estimates of reef habitat areas in Indonesia. Quotas depend heavily on successful implementation and are one of several possible approaches to achieving sustainable exports of a CITES Appendix II listed species.

CONTENTS

GLOSSARY OF ACRONYMS

BKSDA	*Balai Konservasi Sumber Daya Alam* (Regional Office for the Conservation of Natural Resources, under the jurisdiction of PHKA, Indonesian Ministry of Forestry)
BPPT	*Badan Pengkajian dan Penerapan Teknologi* (Agency for the Assessment and Application of Technology)
CITES	Convention on International Trade in Endangered Species of Wild Fauna and Flora
CRRF	Coral Reef Research Foundation
DKP	*Departemen Kelautan dan Perikanan* (Ministry of Marine Affairs and Fisheries)
GBR	Australian Great Barrier Reef
GIS	Geographic Information System
GPS	Global Positioning System
HHW	humphead wrasse (= Napoleon fish)
IUCN	The World Conservation Union
IUU	illegal, unreported and unregulated fishing
LIPI	Indonesian Institute of Sciences (the CITES scientific authority of Indonesia)
MCMC	Markov Chain Monte Carlo
NDF	**N**on-Detrimental Findings
PHKA	*Perlindungan Hutan dan Konservasi Alam* (the Directorate General of Forest Protection and Nature Conservation, under the Ministry of Forestry), the CITES Management Authority of Indonesia
SSB	spawning stock biomass
TL	total length
UVS	underwater visual survey

1. INTRODUCTION

The Napoleon fish (= humphead wrasse, Maori wrasse), *Cheilinus undulatus*, is the largest living member of the family Labridae, with a maximum size exceeding 2 m and 190 kg. The species is a protogynous hermaphrodite (i.e. adults can change sex from female to male), has a low productivity and occurs in naturally low densities in reef-associated areas throughout its geographical range in the Indo-Pacific (Sadovy *et al*., 2003; Figure 1). Recorded maximum adult densities rarely exceed 10 fish/10 000 m^2 and are at least 10-fold less in areas affected by fishing. The species is one of the most vulnerable to the impacts of fishing in reef fish assemblages. Substantial declines in local abundance have been observed in many locations within the species' range due to several factors, but most prominently because of trade-driven overfishing (Sadovy *et al*., 2003). Napoleon fish has a high value in the live reef food fish markets, with recent average retail prices of live fish in the Hong Kong market reaching US$60 per kilogram (Sadovy *et al*., 2003). The species is occasionally marketed chilled.

The Napoleon fish was included in the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) Appendix II in 2004 (http://www.cites.org/eng/app/appendices.shtml) because of its vulnerable status and the ongoing threat to its conservation from international trade. Responding to the need for sustainable international trade that results from this listing is a challenge for both exporting and importing countries. Failure to successfully manage the international trade in this species could ultimately lead to a proposal for Appendix I listing which, if successful, would mean a total international trade ban. Indeed, some countries, such as the Philippines, have already opted to ban exports of all Appendix II-listed species, because of the difficulties of implementing the necessary trade and fishing controls.

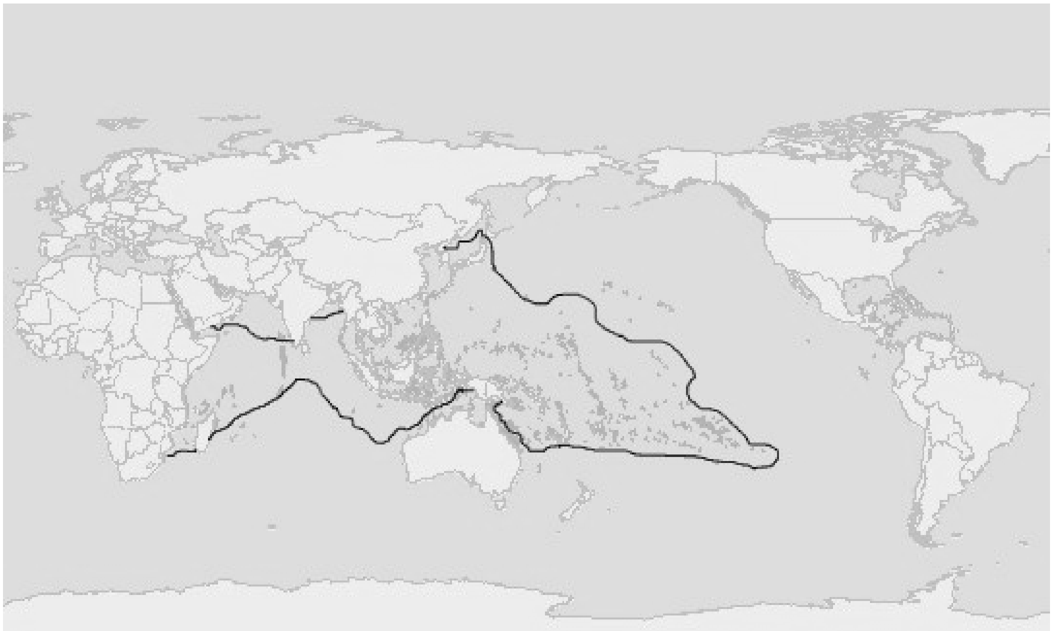


Figure 1. Area of distribution of Napoleon fish (line). The species is closely associated to coral reefs within its range.

The Napoleon fish was the first commercially important coral reef food fish to be listed on CITES Appendix II. Under CITES regulations, countries exporting Appendix II species are required to demonstrate that export quotas are derived from legal fisheries and that such exports will not be detrimental to the survival of the species or its role in the ecosystem (Non-Detrimental Findings – NDF). According to an operational definition proposed by Rosser and Haywood (2002), "an export for international trade is not detrimental when it is part of a catch, the sum of which is sustainable, in that it does not result in unplanned range reduction, or long-term population decline, or otherwise changes the population in a way that might be expected to lead to the species being eligible for inclusion in Appendix I" (Appendix I is reserved for species threatened with extinction and for which commercial international trade is prohibited).

An NDF requirement involves several facets, including a scientific basis for defining a sustainable level of removals from the exploited stock or population. From the point of view of responsible fisheries management, an NDF implies defining and enforcing a catch level that maintains the abundance of the stock above a state where it would be considered overfished or depleted and that would have a negative impact on the ecosystem (Medley, 2005). The problem is that information about the targeted resources is often so poor for many fisheries that it is very difficult to make inferences about their status or about sustainable catches. It has been shown that data limitation is particularly prominent in areas with high species diversity and small stocks, and where fisheries play an important role for food security, such as in many tropical, low-income countries of Africa, Asia, Oceania and the Caribbean (Vasconcellos and Cochrane, 2005).

Recognizing the gravity of the problem of data limitation in fisheries, FAO implemented a "Strategy for Improving Information Status and Trends of Capture Fisheries", developed as a voluntary instrument complementary to the Code of Conduct for Responsible Fisheries (FAO, 2003). The Strategy calls the attention of States to the fact that many small-scale fisheries, particularly in developing countries, are not well monitored and, consequently, are not adequately considered in the development of plans and policies for fisheries. It also recognizes the development of approaches for fisheries assessments in data-poor situations as one of the key areas of action for improving information on status and trends of marine capture fisheries (FAO, 2003).

Following the CITES Appendix II listing in 2004, exporting countries, mainly in Southeast Asia, are required to develop an NDF for the Napoleon fish. Given the paucity of information on reef fish species in general in the region, including for the Napoleon fish, a generic model was proposed to assist countries that wish to develop sustainable export quotas for the species. Initiated with the close collaboration of Indonesia, the major exporter of the Napoleon fish, in 2005, this generic approach found strong support from other countries at an international workshop held in June, 2006, in China, Hong Kong Special Administrative Region (Hong Kong SAR)[1], given the widely acknowledged need for management guidelines for coral reef associated fisheries in the region (Chu *et al.*, 2006). The development of a sustainable export quota was particularly appropriate for Indonesia because "quota" is the principle measure adopted to control international trade in threatened species by the country.

Data limitation is a conspicuous problem in the small-scale capture fisheries of Indonesia and represents an important constraint for decision-making in the management of coastal fisheries (e.g. Pet-Soede, 2000). Indonesian fisheries are very complex, a reflection of the country's highly diverse geographic characteristics, high species diversity and population densities. Indonesia has one the largest concentrations of marine biodiversity in the world. Coastal waters contain 18 percent of the global tropical coral reefs and the highest diversity of coral reef fish in the world (Burke, Selig and Spalding, 2002). Overall, the fishing industry makes a very important contribution to the national diet, providing nearly two-thirds of population's animal protein (FAO, 2000). Small-scale fisheries produce about 95 percent of total marine fisheries production. Many small-scale fishermen are confined to coral reefs, with many using non-powered boats, such as dugout canoes, to access fishing grounds that are in waters close to their home base. These fisheries employ a variety of gears, including gillnets, cast nets, traps, seines and hook-and-line. It was estimated that more than 80 percent of the small-scale fishers and their families have net incomes below the national threshold poverty level (FAO, 2000).

Indonesia is the major exporter of Napoleon fish to the international live food fish markets, and also represents a significant proportion of the species geographic range. Napoleon fish can be taken from reef areas by hook and line, but they are not easy to catch so they are more readily, and quite widely in Indonesia, caught using cyanide. Fishers expose the fish to cyanide which affects oxygen uptake at

[1] China, Hong Kong Special Administrative Region: herewith after referred to as China, Hong Kong SAR.

the gills and slows the fish down. The fisher is then able to remove the fish by hand before the toxin kills it. Nowadays fishing pressure for the species seems to be heavier in eastern Indonesia where cyanide is more often used. After capture, Napoleon fish are taken to the holding pens of local small- or large-scale fish collectors. Fish may then be collected by mother ships that regularly move among communities to collect live fish, either for direct export or to move the fish to an exporting facility. Alternatively, if the fish is too small for market (there is a preferred market "plate-size" which gets the best prices) the young fish are kept in cages and fed until they reach market size; this is called "grow-out" or "net culture". Grow-out is extensively practiced in Indonesia, Malaysia and the Philippines and probably accounts for a significant percentage of all fish traded live on international markets. Most fish that remain alive are exported, either by sea (most fish) or by air. The trade routing is complex and not fully understood either within Indonesia or between Indonesia and Chinese consumer centres (Sadovy, 2006). Singapore may be a major export destination before onward shipments northwards, but trade in marine commodities between Indonesia and Singapore is not well documented. A significant number of dead fish enter domestic markets, where their value is considerably less than in the live trade.

Following the listing of Napoleon fish in CITES Appendix II, the CITES Authorities of Indonesia established an export quota of 8 000 fish per year as an interim measure pending further information. The initial quota was determined based on discussions with traders in Indonesia and export figures, and was 10-fold less than the previous quota of 70 000–80 000 fish. Subsequently, the Indonesian Institute of Oceanography (LIPI), which is the CITES national scientific authority, became involved in collaborative work with the IUCN (The World Conservation Union) Groupers & Wrasses Specialist Group and the FAO to develop an approach for NDF to further refine an export quota for the species. This report describes the approach developed and the preliminary results obtained under this joint collaborative work, with recommendations for general application by exporting countries and a description of complementary projects.

The general approach for calculating a sustainable level of catch involves the following steps:

(a) use of a population dynamics model to select the rate of fishing mortality that achieves a user-specified management goal (e.g. to achieve a long-term catch of maximum sustainable yield, or to keep the population size above some threshold level, such as 20 percent or 40 percent of the unfished level);

(b) calculation of the current size of the population; and

(c) multiplication of the current population size by the exploitation rate, which leads to the catch limit.

The modelling and estimation framework, outlined in Section 2 of this report, is tailored to a protogynous hermaphrodite as well as to the specifics of the fishery for Napoleon fish in Indonesia. Specifically, the number of males depends on the number of females and the rate of sex-change, while allowance is also made for size-specific fishing selectivity and grow-out of caged animals. The calculation of sustainable catch allows for the allocation of the target catch amongst various uses (domestic use, export use) and for adjustments to the export quota to account for losses due to mortalities in transit and illegal exports. It is very important to factor in all uses of the resource (for example, mortality of live fish and estimates of illegal trade) when establishing a sustainable annual catch. This is because it is the sum of all catch, legal and illegal, that must be demonstrated to be sustainable to satisfy the NDF requirement under CITES Appendix II, which cannot be assessed just by the numbers of fish exported. Although the price paid to fishers and the retail prices are substantially lower for dead than for live fish, there is still a substantial domestic market for dead fish in Indonesia, as indicated by the FAO landings for 2004 for this species. The prices for dead Napoleon fish in Southeast Asia are similar to those for most other chilled reef fishes, while in the western Pacific, dead Napoleon fish can fetch a good price, but live fish are not commonly exported.

The yield model developed for Napoleon fish is specific to a protogynous species, and requires that the values of its parameters be specified. Calculation of export quotas also requires information on the current abundance of the population in absolute terms and its size-structure. However, data for Napoleon fish are very limited, as for most coral reef fishes. Specifically, there is no long-term index of abundance for this species, either globally or locally, which could form the basis for a stock assessment based on fitting a population dynamics model to estimate current abundance. It should be noted, however, that such problems are characteristic of assessments and risk analyses for many coral reef fishes. The ability therefore exists within the assessment framework to examine the implications of alternative assumptions and parameter values. For example, Monte Carlo simulation can be used to quantify parameter uncertainty and uncertainty about current abundance, which then allows the results (the level of catch) to be expressed as a probability distribution reflecting uncertainty. A precautionary approach to handling uncertainty would be to base any export quota on a lower percentile of the probability distribution for the export quota, rather than the "best" estimate, especially if there is an intention for population recovery.

The model, and the estimation of its parameters, are based on the best available scientific information and can be modified as more information becomes available. The approach for calculating export quotas can be adapted for use in other countries/areas by setting the parameter values based on the local situation and data. As noted throughout this report, there are many uncertainties related to parameters and the assumptions of the model, owing to a lack of basic biological information and a limited understanding of processes affecting fisheries and fish population dynamics. Caution must therefore be applied, and due consideration for the sources of uncertainties taken into account, when using the model to provide management advice.

The sustainable annual catch suggested by the model should be considered as part of an adaptive approach to managing the Napoleon fish. An adaptive management approach assumes that any quota set will be effectively enforced and will be modified appropriately in response to periodically repeated monitoring of stock condition and assessments of enforcement effectiveness by both importing and exporting countries. The quota and level of enforcement may need to be adjusted according to whether subsequent monitoring of Napoleon fish indicates recovery, no recovery or further declines. Failure of enforcement will lead to further declines in species numbers.

Section 2 of this report outlines the conceptual framework for the calculation of the quantities needed to determine an export quota. It then provides the mathematical specifications for the population dynamics model and how information from underwater visual surveys is used to estimate current population size and its uncertainty. Section 2.3 explains how the parameters of the population dynamics model were estimated for the application to Napoleon fish in Indonesia, with some of the details of the applications included in the Appendices. In Section 3, preliminary estimates of a sustainable export quota are calculated following the presentation of model parameterization, preliminary model validation and the estimation of stock abundance. Considering that the stock assessment approach developed in this report may appear complex for people without a strong fisheries science background, a user friendly graphical interface was developed to facilitate the use of the approach in setting export quotas. The user interface is documented in Appendix D.

Areas in which the collection of additional data could further refine parameter estimates and improve the calculations are identified in Section 4.1. One aspect of the model that needs further work in particular is the estimation of reef area, as this is critical for abundance estimation. Recent work using Landsat imagery and a Geographic Information System (GIS) approach, likely to be far more representative of true reef area, indicates that the current approach used for estimating reef area (Spalding, Ravilious and Green, 2001) may overestimate the true reef area by a factor of two or more (Andrefouet *et al*., 2006). In addition, not all shallow coastal areas might be appropriate habitat for the Napoleon fish. For example, juveniles are found in live corals and adults are typically associated with reef slopes close to deeper waters. The present analyses, however, use the estimate of reef area for Indonesia obtained by Spalding, Ravilious and Green (2001) as calculations to update the estimate of reef area for Indonesia have yet to be completed. The estimate of reef area is likely to change (be reduced), possibly substantially, once the new calculations are completed (FAO, in prep.).

2. METHODS

2.1 Conceptual framework

Figure 2 illustrates the conceptual framework on which the analyses of this report are based. A population dynamics model is used to determine three relationships: (1) between the rate of fishing mortality in the wild and the expected catch (in the wild and from caged animals); (2) between the rate of fishing mortality in the wild and the reduction in population size (measured by, for example, total female biomass, or egg production); and (3) between the rate of fishing mortality in the wild and the sex-ratio (females per male) of mature animals. These relationships can be used to calculate a variety of biological reference points. The following biological reference points can be computed using the model at present:

(a) F_{MSY} – the rate of fishing mortality at which the catch (in numbers or in mass) is maximized;

(b) $F_{20\%}$ – the rate of fishing mortality at which the spawning biomass is reduced to 20 percent of its unfished level; and

(c) $F_{F:M}$ – the rate of fishing mortality at which the sex ratio (females per male) is double that in an unfished state.

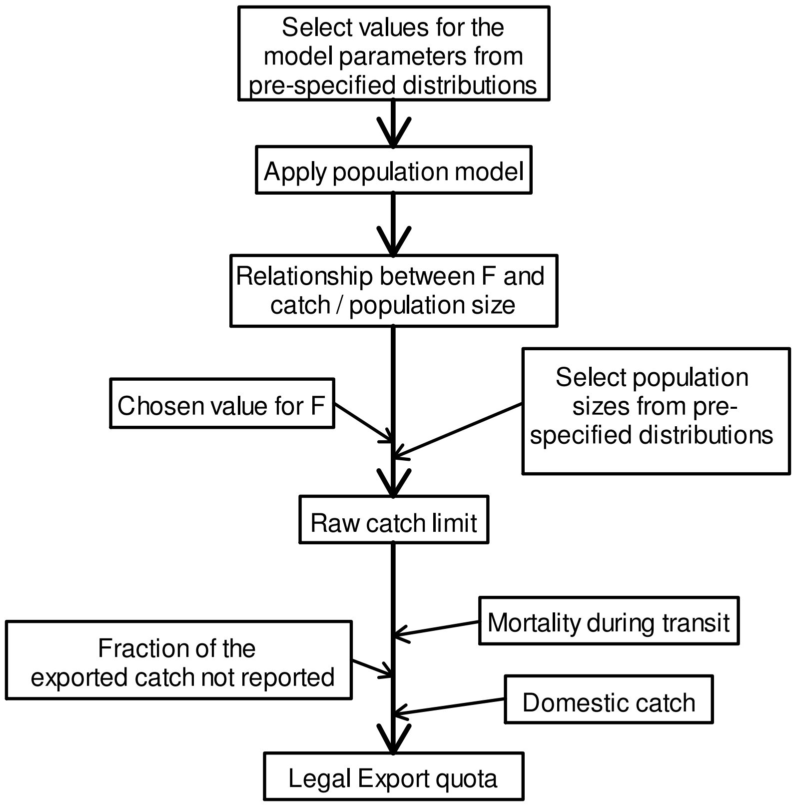


Figure 2. Outline of the framework on which the analyses are based.

Figure 3, which illustrates the relationship between the rate of fishing mortality and catch/population size for a hypothetical set of parameter values, highlights how the first two of these three biological references points are calculated (i.e. the outcome of the first two steps in Figure 2).

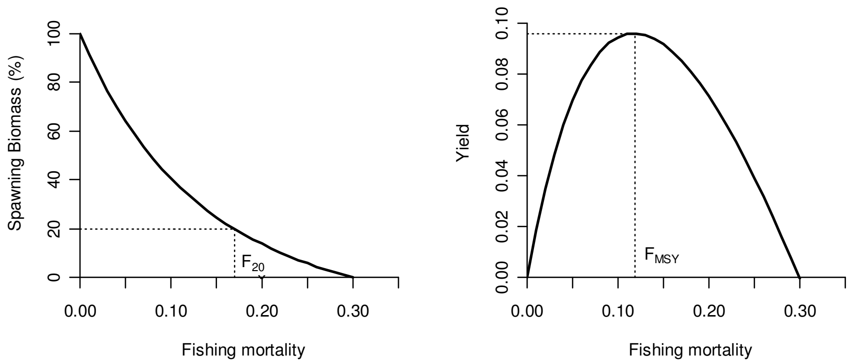


Figure 3. Relationship between spawning biomass and fishing mortality (left) and that between catch and fishing mortality (right). The dotted lines indicate the values for two biological reference points ($F_{20\%}$; F_{MSY}).

Figure 3 is based on a single set of values for the parameters for the population dynamics model. However, several parameters of this model may be very uncertain. This uncertainty can be represented by drawing values for the model parameters from distributions that represent their uncertainty. The impact of this is illustrated in Figure 4, which shows a distribution for F_{MSY} after accounting for uncertainty in two of the key parameters of the population dynamics model (steepness[2] of the stock-recruitment relationship and the rate of natural mortality). Depending on the attitude towards uncertainty, a value for the fishing mortality on which the export quota is to be based can be chosen by, for example, taking the central value in Figure 4 (risk neutral approach to uncertainty) or a lower percentile (risk averse approach to uncertainty).

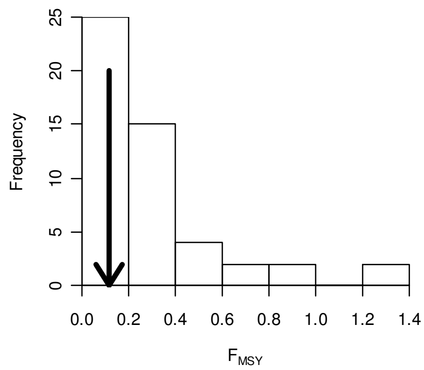


Figure 4. Histogram of F_{MSY}, accounting for uncertainty in natural mortality and the steepness of the stock-recruitment relationship. The arrow indicates the value of F_{MSY} for the parameter values on which Figure 3 is based.

Once a value for the "target" rate of fishing mortality is chosen by the user of the approach, it can be used to compute a "raw catch limit" (Figure 2). However, the live reef fish trade presents several challenges related to calculating an export quota. Specifically, account needs to be taken of the extent of illegal, unreported and unregulated (IUU) export out of source countries, the mortalities of fish during transit between capture and the point of transport departure (because this is a trade in live animals), as well as domestic use. The export quota is therefore calculated as the "raw catch limit" less domestic removals and the impact of IUU exports and mortalities in transit after capture but before export.

[2] Steepness is defined after Francis (1992) to be the fraction of the average pre-exploitation recruitment expected when the spawning biomass is reduced to 20% of the pre-exploitation level.

2.2 Calculating biological reference points using a yield model

The biological reference points are based on the combination of a per-recruit model and a model of the relationship between reproductive output and subsequent recruitment (*sensu* Sissenwine and Shepherd, 1987). Unlike most models used to calculate biological reference points, the model of the population dynamics on which the analyses of this report is based is age-, sex- and size-structured with the number of males depending on the number of females and the rate of sex-change (practically all Napoleon fish are born females and most change sex between 55 and 75 cm). The number of females is divided into those in the wild and those in cages. The number of females (assumed to be females because of small sizes) in cages depends in turn on the selection pattern of the fishing gear, the number of females in the wild, and the proportion of females that are sent to cages rather than being exported. Grow-out operations are relevant for exports rather than domestic use since exports tend to be of live fish and domestic use is reportedly predominantly that of dead fish. The model assumes that fishing and natural mortality occur throughout the year, followed by growth and then sex-change. This order of events during the year was selected primarily for computational convenience – the results are unlikely to be markedly sensitive to whether sex-change is assumed to occur before or after growth.

The dynamics of all natural populations are governed by both density-independent and density-dependent processes. Density-dependence can be expressed in the form of compensation (lower per capita population growth rate at high population size) or depensation (lower per capita population growth rate at low population size). The direct evidence for depensation in marine fishes is relatively weak (e.g. Liermann and Hilborn, 1997) although that for compensation is much stronger. There are many possible ways in which density-dependence could be expressed (e.g. growth, fecundity, maturity, sex-change, and survival). The most common way to model density-dependence, however, is to assume that the survival rate of age-0 animals (or the rate of settlement of age-0 animals) is density-dependent, and this is how density-dependence is expressed in the model.

Density-dependence is modelled as a Beverton-Holt (Beverton and Holt, 1957) function of the gonad weight of mature females, possibly impacted by an unbalanced sex-ratio. The latter impact is modelled by assuming that fertilization rates are unaffected by changes in the number of females per male until the ratio of females to males reaches a critical level after which the fertilization rate is assumed to decline exponentially with further deviations from the critical number of females per male. The impact of an unbalanced sex-ratio on the fertilization rate is the only source of depensation in the model. Other possible sources of depensation, such as those that might be a function of low density, are not factored into the model since there is no information to parameterize their effects.

The model pertains to a single homogenous population. This assumption is not ideal for Napoleon fish which, like many coral reef fishes, forms a meta-population, in which sub-populations are linked via larval advection, adult movement or both (depending on species). The data for Napoleon fish do not currently allow detailed metapopulation models to be developed (such models have, however, been developed for common coral trout on Australia's Great Barrier Reef; Little *et al*., in press).

2.2.1 Basic population dynamics

The numbers-at-age and -size for females in the wild and in net cages are governed by the equation:

$$N_{a+1,\mathrm{f},l,\mathrm{w}} = (1-\alpha_l)\sum_{l'} X_{\mathrm{f},l',l} N_{a,\mathrm{f},l',\mathrm{w}}\, e^{-(M+S_{l'}F)} \tag{1a}$$

$$N_{a+1,\mathrm{f},l,\mathrm{c}} = \sum_{l'} X_{\mathrm{f},l',l} N_{a,\mathrm{f},l',\mathrm{c}}\, e^{-(M'+\tilde{F}_{l'})} + \sum_{l'} X_{\mathrm{f},l',l} \frac{\beta_{l'} S_{l'} F}{M+S_{l'}F} N_{a,\mathrm{f},l',\mathrm{w}} (1-e^{-(M+S_{l'}F)}) \tag{1b}$$

where $N_{a,s,l,\mathrm{w}}$ is the number of animals of age a and sex s in size-class l in the wild at the start of the year,

$N_{a,s,l,\mathrm{c}}$ is the number of animals of age a and sex s in size-class l in cages at the start of the year,

$X_{s,l',l}$ is the size-transition matrix for animals of sex s (the fraction of animals of sex s in size-class l' that grow into size-class l during the year),

M is the instantaneous rate of natural mortality for animals in the wild (assumed to be independent of age, sex and size),

M' is the instantaneous rate of natural mortality for animals in cages,

S_l is the selectivity of the fishing gears on animals in size-class l in the wild,

$\tilde{F}_l$ is the fishing mortality on animals in size-class l in cages:

$$\tilde{F}_l = \begin{cases} 0 & \text{if } \bar{l} \leq G \\ \infty & \text{otherwise} \end{cases}$$

F is the fully selected fishing mortality for wild-caught fish, i.e. the fishing mortality on fish for which $S_l = 1$,

G is the length at which grown-out fish are exported,

β_l is the length-specific proportion of animals that are placed in cages rather than being exported, and

α_l is the probability that an animal in size-class l changes sex.

The first term on the right hand side of Equation 1b represents the growth and survival of females that were in cages at the start of the year while the second term represents females that were captured during the year and caged. The fraction of the catch that is sent to cages depends on the vector β. Note that growth occurs while fish are in cages, but the model ignores the possibility of sex-change while in cages, primarily because very few caged animals would reach the size at which sex-change would occur.

The dynamics of the numbers-at-age for males are similar to those for females except that account needs to be taken of females becoming males because of the impact of sex-change, i.e.:

$$N_{a+1,\mathrm{m},l} = \sum_{l'} X_{\mathrm{m},l',l} N_{a,\mathrm{m},l'}\, e^{-(M+S_{l'}F)} + \alpha_l \sum_{l'} X_{\mathrm{f},l',l} N_{a,\mathrm{f},l',\mathrm{w}}\, e^{-(M+S_{l'}F)} \qquad (2)$$

The initial conditions for this model correspond to 1 female of age 0 in the lowest size-class.

2.2.2 Catches

The catches by sex (in numbers and in biomass) are given by:

$$\begin{aligned}
C_{\mathrm{N,f}} &= R\sum_a \sum_l N_{a,\mathrm{f},l,\mathrm{w}} \frac{(1-\beta_l)S_l F}{M+S_l F}(1-e^{-(M+S_l F)}) + R\sum_a \sum_{l|\bar{l}_l>G} N_{a,\mathrm{f},l,\mathrm{c}} \\
C_{\mathrm{N,m}} &= R\sum_a \sum_l N_{a,\mathrm{m},l,\mathrm{w}} \frac{S_l F}{M+S_l F}(1-e^{-(M+S_l F)}) \\
C_{\mathrm{B,f}} &= R\sum_a \sum_l w_l N_{a,\mathrm{f},l,\mathrm{w}} \frac{(1-\beta_l)S_l F}{M+S_l F}(1-e^{-(M+S_l F)}) + R\sum_a \sum_{l|\bar{l}_l>G} w_l N_{a,\mathrm{f},l,\mathrm{c}} \\
C_{\mathrm{B,m}} &= R\sum_a \sum_l w_l N_{a,\mathrm{m},l,\mathrm{w}} \frac{S_l F}{M+S_l F}(1-e^{-(M+S_l F)})
\end{aligned} \qquad (3)$$

where $C_{\mathrm{N},s}$ is the catch of animals of sex s in numbers,

$C_{\mathrm{B},s}$ is the catch of animals of sex s in mass,

R is the number of 0-year-olds expected given the current rate of fishing mortality (see Section 2.2.4),

w_l is the mass of an animal in size-class l:

$$w_l = \tilde{a}\bar{l}_l^{\tilde{b}} \tag{4}$$

$\bar{l}_l$ is the mean length of an animal in size-class l (set equal to the length corresponding to the mid-point of size-class l), and

$\tilde{a}, \tilde{b}$ are the parameters of the length-weight relationship.

2.2.3 Growth

The size-transition matrix is computed using the following approximation to the probability density function for a random individual in size-class l' growing into size l over a year:

$$X_{s,l',l} = \Phi_{s,l',l} / \sum_{l''} \Phi_{s,l',l''} \qquad \Phi_{a,l',l} = \exp\left[-\frac{(\bar{l}_l - [\ell_{\infty,s}(1-e^{-\kappa_s}) + \bar{l}_{l'}e^{-\kappa_s}])^2}{2\sigma_s^2}\right] \tag{5}$$

where $\ell_{\infty,s}$, κ_s are the parameters of the von Bertalanffy growth curve for animals of sex s, and

σ_s is the standard deviation of the growth increment, assumed to be independent of age and current size.

2.2.4 Density-dependence

Density-dependence is assumed to be proportional to the gonad weight of ripe (i.e. with vitellogenic stage oocytes or later) females (because gonad weight should be a better measure of reproductive output than, for example, fish mass), and to affect the survival rate of age-0 animals, i.e. for the case in which density-dependence is governed by the Beverton-Holt function:

$$R = \frac{4hR_0E}{R_0\tilde{E}_0(1-h) + (5h-1)E} \tag{6}$$

where E is the gonad weight of ripe females:

$$E = Q\sum_a \sum_l N_{a,\mathrm{f},l,\mathrm{w}} f_l \, g_l \tag{7}$$

f_l is the proportion of females in size-class l that are mature:

$$f_l = \begin{cases} 0 & \text{if } \bar{l}_l < l_{\min,\mathrm{f}} \\ (1+\exp(-\ell n 19(l - l_{50,\mathrm{f}})/(l_{95,\mathrm{f}} - l_{50,\mathrm{f}})))^{-1} & \text{otherwise} \end{cases} \tag{8}$$

$l_{50,\mathrm{f}}, l_{95,\mathrm{f}}, l_{\min,\mathrm{f}}$ are the parameters of the relationship between length and being mature,

g_l is the gonad weight for a ripe female in size-class l:

$$g_l = a_g\, e^{b_g \bar{l}_l} \tag{9}$$

a_g, b_g are the parameters of the relationship between gonad weight and length for females,
Q determines the impact of sex-ratio on fertilization rates:

$$Q = \begin{cases} 1 & \text{if } \chi < \chi_c \\ \exp(q[\chi - \chi_c]) & \text{otherwise} \end{cases} \tag{10}$$

χ is the sex-ratio (females per male) for the current level of fishing mortality,
χ_c is the critical sex-ratio above which fertilization rates decline,
q is the parameter that determines how rapidly fertilization rates decline with increasing sex-ratio,
h is the "steepness" of the stock-recruitment relationship,
R_0 is the virgin number of 0-year-olds (set to 1 without loss of generality), and
$\tilde{E}_0$ is the gonad weight of ripe females-per-recruit in the absence of exploitation.

Equation 6 can be solved for the number of 0-year-olds as a function of the gonad weight of ripe females-per-recruit, $\tilde{E}$, i.e.:

$$R = \frac{4hR_0\tilde{E} - R_0\tilde{E}_0(1-h)}{(5h-1)\tilde{E}} \tag{11}$$

2.2.5 Output parameters

The key outputs of the model are the catches (by sex) in numbers and in mass (Equation 3), the number of mature males and females, the biomass of mature males and mature females, the gonad weight of females (Equation 7), and the sex-ratio (mature females per male). The quantities related to the numbers and biomass of spawning animals are given by:

$$H_{\mathrm{N,f}} = R\sum_a \sum_l f_l\, N_{a,\mathrm{f},l,\mathrm{w}}\;; \qquad H_{\mathrm{N,m}} = R\sum_a \sum_l N_{a,\mathrm{m},l} \tag{12a}$$

$$H_{\mathrm{B,f}} = R\sum_a \sum_l w_l\, f_l\, N_{a,\mathrm{f},l,\mathrm{w}}\;; \qquad H_{\mathrm{B,m}} = R\sum_a \sum_l w_l\, N_{a,\mathrm{m},l} \tag{12b}$$

2.3 Model parameterization and quantification of uncertainty

Table 1 lists the values for the parameters of the yield model. The following sub-sections provide the basis for these values.

Table 1. Values for the biological parameters of the yield model. Lengths are specified in terms of total length.

Quantity	Males	Females	Source
Length-weight relationship			
Length-weight *a*, $\tilde{a}$	0.000023178		Sadovy *et al*. (2003)
Length-weight *b*, $\tilde{b}$	2.9589		Sadovy *et al*. (2003)
Growth curve			
Von Bertalanffy ℓ_∞	91.5 cm	168.4 cm	Section 3.1.1
Von Bertalanffy κ	0.131 yr^{-1}	0.0675 yr^{-1}	Section 3.1.1
Variance in growth increment σ	19.5 cm^2	19.5 cm^2	Section 3.1.1
Maturity-length relationship			
First length-at-maturity, $l_{\text{min,f}}$	35 cm		Section 3.1.3
Length-at-50%-maturity, $l_{50,\text{f}}$	35 cm		Section 3.1.3
Length-at-95%-maturity, $l_{95,\text{f}}$	68.2 cm		Section 3.1.3
Gonad weight-length relationship			
Gonad weight-length *a*, a_g	12.816		Section 3.1.3
Gonad weight-length *b*, b_g	0.0025		Section 3.1.3
Density-dependence			
Steepness, *h*	Logit(*h*) ~ N(0.891, 0.912^2)		Section 3.1.4
Critical sex-ratio, χ_c	50		Section 3.1.4
Sex-ratio impact rate, *q*			User-specified
Parameters related to grow out			
Natural mortality (cages), *M'*	0.134 yr^{-1} (± 0.064)		Section 3.1.5
Fraction caged, β_l	1 for size < 25 cm		Section 3.1.5
Length-at-export, *G*	Trapezoidal 30, 40, 50, 55 cm		Sachoemar, Suharti and Sadovy (2006)
Other parameters			
Natural mortality, *M*	0.106 yr^{-1}		Section 3.1.2
Selectivity (wild), S_l			
Constant term, ϕ	0.0281		Section 3.1.6
Length-at-modal selectivity	34.261		Section 3.1.6
Variance of selection function, σ_S	0.0838		Section 3.1.6
Fishing mortality (wild), *F*			User-specified
Rate of sex change, γ	0.04 - 0.27 yr^{-1}		Section 2.3.7
Length range for sex change	55 – 75 cm		Section 2.3.7
Quota calculation			
Amount consumed domestically	115 t		See Appendix B
Post-harvest mortality	N/A		See Appendix B
Proportion unreported	0.46		See Appendix B

2.3.1 Growth

The size-transition matrices are determined by the values for ℓ_∞, κ and the extent of variation in length-at-age (see Equation 5). Choat *et al*. (2006) estimate a growth curve by fitting to data on length-at-age for 164 animals. This data set was increased by the addition of further data from the

ELF project[3]. The values for the parameters of the growth model are estimated by fitting Equations 1 and 2 under the assumption that fishing mortality is zero (an assumption that is approximately valid as the bulk of the data came from the Great Barrier Reef where the exploitation rate has been low, at least in recent years). The likelihood function for the data is given by:

$$L \propto \prod_{s} \prod_{i} N_{a_{i,s}, L_{i,s}, w} \tag{13}$$

where $N_{a,s,l,w}$ is the number of animals of sex s and age a in length-class l in the wild if there was one female in the first age- and length-class,

$L_{i,s}$ is the length-class corresponding to the i^{th} fish of sex s, and

$a_{i,s}$ is the age corresponding to the i^{th} fish of sex s.

The data set on which the estimation of the growth curve is based is restricted to data for animals designated to be either males or females (i.e. animals of unknown sex are ignored). Given the nature of the population dynamics model on which Equation 1 is based (an age- and size-structured model that incorporates sex-change), the length of males is directly dependent on the length of females (see Equation 2). This differs from most approaches to fitting growth curves which involve fitting separate (and unrelated) curves for males and females.

2.3.2 Natural mortality

Choat *et al*. (2006) estimated total mortality (Z) to be 0.106 yr^{-1}. An estimate of M can be obtained by regressing the logarithm of the age-frequency on age and then subtracting the rate of fishing mortality from the slope of the regression line. The analyses of this report are based on data collected from the Great Barrier Reef (GBR) Australia, primarily because this is the region for which the most age-composition data are available, but also because fishing mortality for Napoleon fish is generally lower on the GBR than in most parts of Indonesia, so age-frequency curves are more likely to reflect pre-fishing conditions than age-frequencies based on data collected in Indonesia. The use of data from the GBR, however, is based on the assumption that the rate of natural mortality for Napoleon fish is the same across much of the geographic range of the species. Although there are currently no data to validate this assumption, it is common when conducting fisheries stock assessment to use estimates of biological parameters, such as M, estimated for animals in one part of the range for the entire population.

2.3.3 Parameters related to fecundity

Data on maturity-at-length, along with field observations that Napoleon fish do not reach maturity before 35 cm total length (TL), were used to determine the maturity-at-length relationship. Specifically, data on the proportion of fish larger than 35 cm ($= l_{\text{min,f}}$) that are mature by 5 cm size-class were used to estimate the parameters of Equation 8. The yield model assumes that density-dependence depends on the total gonad weight of female spawners (Equation 7). The values for the parameters of Equation 9 were therefore estimated by fitting it to data on gonad weight and length of ripe animals.

[3] The animals from the ELF project, including most of those reported in Choat *et al*. (2004), were collected as part of the CRC Reef Effects of Line Fishing Project (James Cook University, Townsville), either through sampling for the ELF Experiment or during other research tasks. Mapstone *et al*. (2004) outline the basic sampling protocol for the hook and line catch surveys that formed a key part of the ELF Project. These involved the charter of a commercial fishing vessel where sampling effort and fishing gears were standardized, although still characteristic of commercial fishing practices. Standardized fishing effort was distributed uniformly across two depth strata within each of six contiguous blocks that covered the whole perimeter of each of 24 reefs. The ELF Project aims to provide information on all major reef species and not just Napoleon fish. All fish caught during the surveys were measured, tagged for later identification, and kept for weighing and extraction of gonads and otoliths.

2.3.4 Parameters related to density-dependence

Unfortunately, as for reef fishes in general, there are insufficient data to estimate the steepness of the stock-recruitment relationship for Napoleon fish. A Bayesian hierarchical meta-analysis based on the approaches applied by Dorn (2002) and Punt, Smith and Koopman (2005) was therefore conducted for steepness using stock and recruitment data for 12 coral reef-associated fishes (see Appendix A for full details).

2.3.5 Parameters related to grow-out

Unlike most fish population models, the yield model incorporates the fact that exports of Napoleon fish are a mix of catches taken directly from the wild and animals that were taken from the wild and grown-out in cages. It is therefore necessary to determine which (i.e. what size) animals are selected for grow-out, whether the life history parameters (such as growth and natural mortality rates) are the same for animals in cages and those in the wild, and the process of deciding when caged animals are to be exported. The values for these parameters were determined from a survey of collectors. Twenty-six collectors, representing a significant number of total known collectors or culturists from nine regions in Indonesia were surveyed in 2006 either by telephone interview with fishers, collectors and traders or during visits to several grow-out facilities, collectors and traders. Eighteen of the 26 provided sufficient information on the duration of the grow-out period in cages, the fraction of the fish dying while in cages (i.e. mortality rate), and the numbers of fish collected by fishers for use in the model (Sachoemar, Suharti and Sadovy, 2006). More detailed information on the grow-out process is needed to more confidently parameterize this important activity, given the substantial number of fish in international trade that probably go through a grow-out phase (in Indonesia, Malaysia and the Philippines).

2.3.6 Length-specific selectivity

Length-specific selectivity is assumed to be governed by a function that is the sum of a constant and a lognormal density, because this function provides a relatively parsimonious manner to fit the data on selectivity for Napoleon fish:

$$S_l = \phi + (1-\phi)\exp\left[-\tfrac{1}{2\sigma_S^2}(\theta_S - \ell\mathrm{n}\bar{l}_l)^2\right] \tag{14}$$

where ϕ is the background level of selectivity (independent of size),

θ_S is the logarithm of the length-at-modal selection, and

σ_S determines the extent of the selection ogive.

The values for the parameters of this selectivity function are determined by fitting it to data on selectivity as a function of length. The data on selectivity are the ratios of the length-frequency data from surveys of live reef fish food retail and wholesale markets in China, Hong Kong SAR, divided by the population length-frequency inferred from the Underwater Visual Survey (UVS) data (Sadovy *et al*., 2003; Sadovy, 2006, unpubl. data)

2.3.7 Other parameters

The protogynous nature (i.e. adult sex change from female to male) of the Napoleon fish was explicitly represented in the model. Available size/sex data suggests that all or most males are derived from females by sex change rather than from direct development during the juvenile phase. Sex-change is size-dependent and the minimum size after which sex-change may occur is about 55 cm (based on data from GBR, Australia). In principle, the length-at-sex-change could be density-dependent, but this possibility is not included in the current model, owing to the general lack of data on sex-change for the species and particularly the lack of any information on the relationship between the length-at-sex-change and density. Females would not develop into males if they have not done so after reaching 75 cm in length. The proportion of females that change sex in this size range is uncertain, but it is suspected that many fish stay female all their life, given that the population is heavily female biased. In the absence of better information, therefore, a wide range of hypotheses was considered when applying the model. Specifically, it was assumed that between 1/3 and 19/20 (or 95 percent) of females change into males in the size range 55-75 cm, i.e. sex-change was assumed to occur at a constant rate γ between 55 and 75 cm:

$$\alpha_l = \begin{cases} \gamma & \text{if } 55\text{cm} < \bar{l}_l < 75\text{cm} \\ 0 & \text{otherwise} \end{cases} \tag{15}$$

where the rate of sex change, γ, was estimated assuming that sex change occurs exponentially between 55 and 75 cm (approximately equivalent to ages (t) of 9 and 20 years), i.e.

$$N_{males,75cm} = N_{females,55cm} e^{-\gamma t} \tag{16}$$

Assuming that between 1/3 and 19/20 of females change into males in this age/size range, the rate of sex change (γ) was therefore estimated to lie between 0.04 and 0.27 year^{-1}. Alternative functional representations of sex change with size/age could be tested when more information becomes available. Although the effect of these alternative representations on model outputs has not been tested, it is reasonable to assume that the wide range of rates of sex change used in the model captures the uncertainty about this biological process adequately.

2.4 Abundance estimation

Underwater Visual Surveys (UVS) were done to document the natural density of Napoleon fish in areas of "low", “medium” and "high" fishing intensity. Table 2 provides the qualitative criteria used to assign sites to fishing intensity classes. These criteria were selected based on reasonable and practical criteria to enable a qualitative indication of fishing intensity to be determined, with the objective of making an estimate of the percentage of Indonesia’s reefs under different levels of fishing intensity. The criteria can be used in any country. Population density information, combined with an estimate of the total reef area for the country, was used to estimate fish abundance. Six surveys (see Table 3a; Figure 5) were done using the "GPS (Global Positioning System) Density Survey" method developed by Pat Colin of the Coral Reef Research Foundation (CRRF) and Y. Sadovy (Sadovy, 2005, 2006). This method is particularly well-suited to assessing the abundance of uncommon and wide-ranging species, such as Napoleon fish. Even in relatively undisturbed regions, Napoleon fish are among the least common of the commercially exploited reef fishes, and specifically tailored appropriate methods are needed to survey them in the field.

The GPS density survey method uses a "position logging" GPS receiver in a water-proof floating housing which is towed on the surface by the observer. The GPS logs its position every 15 seconds, allowing an accurate record of the track surveyed. Fish within a predetermined distance either side of the swim track (up to 10 m in clear water and depending on depth, giving a total "swath" or a maximum scan width of 20 m) are surveyed by swimming along a reef feature or in a relatively straight line at a steady pace or drifting with currents. The real time that any target fish is observed is recorded on an underwater slate, and the estimated length of the fish is noted.

Logged data from the GPS are downloaded using Garmin Map Source World Map software to provide a permanent record of the area surveyed. Aside from documenting the swim track location, this also allows for replication of the survey track in the future since the tracks are latitude-longitude referenced. Using the concurrent time log and the time of fish observations, the position on the track where any fish was observed can be closely (within a few m) determined from the time and position data. The distance (and thereby the area, depending on swath width) covered during a given survey is documented and the number of fish observed provides an estimate of density (fish per unit area). The survey track and fish positions are plotted on LANDSAT images for reference, downloaded from the University of South Florida (http://imars.usf.edu/corals/) (Figure 5).

Table 2. Qualitative criteria used to assign levels of fishing intensity for HHW in Indonesia. The level which most closely fits the circumstances of the survey site under consideration was selected after evaluating all factors. Information to apply these criteria was obtained from interviews with fishermen, underwater surveys, observations of catches, discussions with knowledgeable fishery officers, referral to fishery reports from the area, questionnaires, and demographic data.

FACTOR/Intensity	**High Intensity**	**Medium Intensity**	**Low Intensity**
Fish size in fishery	Mostly juvenile fishes of various species caught (does not include when juvenile HHW are specifically targeted – see below); information on catches showing/suggesting declines in fish size over time.	Some adults are taken in the fishery; some declines in fish size have occurred.	Mainly adults; no indications of any declines in fish size over time with fishing.
Proximity to cities	Close to major urban area.	Accessible to urban areas but not on regular daily basis, or requiring long occasional trips, or seasonally inaccessible. Nearby communities small.	Remote from any population centre or largely inaccessible to fishing for weather or oceanographic reasons, or reef fishes not targeted by local communities.
Historical yield of HHW	Much fishing activity over long term. Information on catches of HHW, if available, suggest marked declines in catch per some unit of effort or fishers have to travel much further or use much more effort to maintain catches; declines in sizes available have declined.	Some activity over medium term (but could also be other combinations of time and intensity between the two extremes).	Little to no current or historical fishing activity.
Common fishing ground	Used by many communities for a long time.	Occasionally used, sometimes intensively, periodically, by a subgroup of fishermen from nearby communities.	Used by just a few individuals.
Catch rates of reef fishes	Other reef fishes in area thought to be heavily overfished as determined by marked declines in catches/CPUE. Fishers have to travel much further and fish much longer to maintain catches when compared to the past.	Commercially important reef fishes in general produce reasonable landings although some declines in CPUE and catches in general and size have been noted; fishers may have to expend a little more effort than before to maintain catches.	Other typically commercial fish species not fished or with little fishing history in area.
Expert fishery officer, biologist opinion in-country	Heavy relative to other areas in the country.	Medium relative to other areas in the country.	Light relative to other areas in the country, or protected effectively from fishing.
Focus on HHW as a target species	Long term (many years) interest in HHW from fishers/traders in live reef fish (small fish main targets) or large fish for spearing.	Recent (last few years) interest in HHW from fishers/traders in live reef fish trade or by spearfishers for dead fish.	No focus on HHW
UVS observations	Severe damage to reef, very little habitat complexity, no large groupers and very few larger fish visible; no HHW visible in UVS or very low densities (see reports for densities).	Loss or marked decline in more vulnerable species from the fishery – medium density as per our medium density site.	Wide size range of fish, including large HHW and densities of > 1 fish / 10 000 m^{-2}. Larger groupers and other vulnerable species present in reasonable numbers.

Table 3. Sources of abundance data from Indonesia, and resultant population length-frequency distributions by fishing intensity class. The length-frequency data for each fishing intensity class were pooled over surveys, sites and transects, without any weighting to construct Table 3b, owing to the sparsity of the data.

(a) Sources of data (6 areas: Banda Is, Derawan, Bali, NW Sulawesi, Raja Ampat, Flores/Sumbawa)

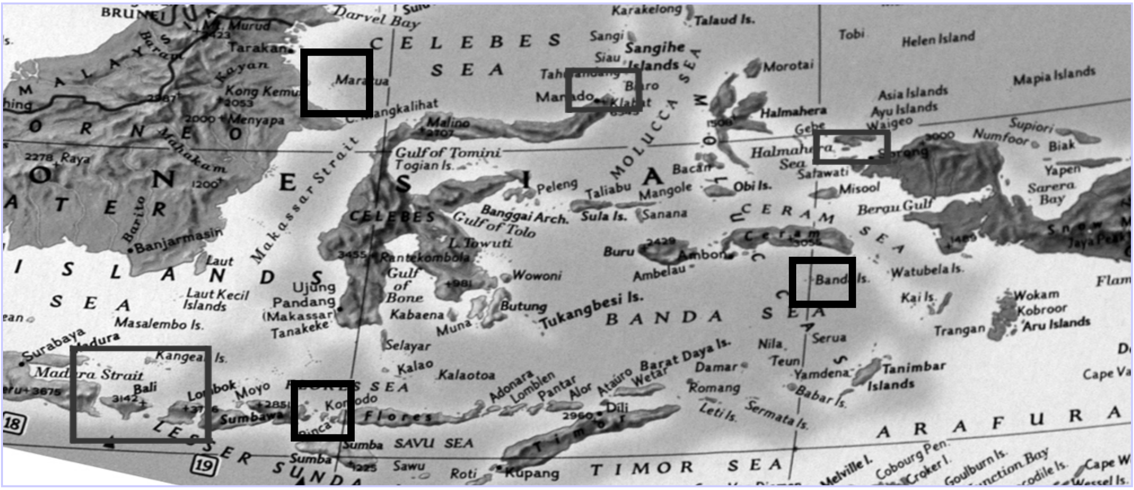
High fishing intensity
- Derawan/Maratua (Sadovy, Colin and Suharti, unpubl.)
- Sumbawa and Flores (Sadovy, 2006)
- North Sulawesi (Sadovy, 2006)
- Bali-Kangean (Sadovy, 2006)

Medium fishing intensity
- Raja Ampat (Sadovy, 2006)

Low fishing intensity
- Bunaken Park, NW Sulawesi (Sadovy, 2006)
- Banda (Sadovy, Colin and Suharti, unpubl.)

(b) Length-frequencies

Length-class TL (cm)	Fishing intensity Low	Medium	High
0-10	1	1	7
10-20	0	1	7
20-30	1	2	5
30-40	10	12	0
40-50	6	26	0
50-60	13	3	0
60-70	18	4	0
70-80	12	3	0
80-90	13	0	0
90100	8	0	0
100-110	4	0	0
110-120	3	0	0
120-130	3	0	0
130-140	0	0	0
140-150	4	0	0
150-160	1	0	0
160-170	0	0	0
170-180	0	0	0
180-190	0	0	0
190-200	0	0	0
Total	97	52	19



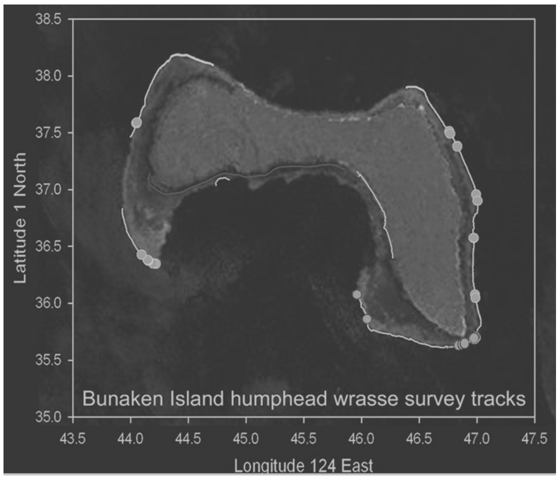


Figure 5. Map of Indonesia (above) showing the six areas where UVS were done for Napoleon fish. For all surveys, GPS was used to identify the exact track followed (shown on the right) and individual fish seen during each survey are marked as circles along each track. The example given is for Bunaken Island, a low fishing intensity area (Sadovy, 2005, 2006).

Population numbers by size-class are obtained by multiplying the raw length-frequencies (Table 3b) by the density for each fishing intensity class, and by the proportion of the total area by fishing intensity class, i.e.: the estimate of the number of animals in size-class l, $\hat{N}_l$, is determined by summing the estimates of the number of animals in size-class l across the three fishing intensity classes:

$$\hat{N}_l = \sum_j \rho_l^j \, A^j \tag{17}$$

where ρ_l^j is the proportion of animals in size-class l for areas with fishing intensity of class j ("high", "medium" and "low"), and

A^j is the total number of animals for areas with fishing intensity of class j.

Estimation of the density for each fishing intensity class cannot be accomplished by simply dividing the total numbers seen during UVS by the total area surveyed because some sites are sampled more intensively than others. Rather, it is necessary to use the count data from UVS to determine densities by site and the probability distribution of densities among sites. A Bayesian hierarchical model that allows the distribution of densities among sites to be computed is used for the purpose. The UVS data for each fishing intensity class can be divided into data by site (e.g. by island) and station within site. The probability models used to represent these data in the Bayesian hierarchical model are:

$$C_{t,i,j} \sim \text{Poisson}\,(D_{i,j}\,E_{t,i,j})$$

$$D_{i,j} \sim \text{Poisson}\,(\mu_j) \tag{18}$$

where $C_{t,i,j}$ is the count for station t for site i within fishing intensity class j,
$D_{i,j}$ is the density at site i within fishing intensity class j,
$E_{t,i,j}$ is the area (m^2) surveyed for transect t for site i within fishing intensity class j (standardized to 10 000m^2), and
μ_j is the mean density across sites with fishing intensity class j.

The prior distribution for $\ell n\mu_j$ is assumed to be U[-10, 3]. The posterior distributions for the parameters of this model are determined using the Markov Chain Monte Carlo algorithm. A total of 10 000 000 cycles were run of which the first 2 000 000 were treated as a burn-in. The chain was then further thinned by defining the posterior distribution using every 1000th element in the chain.

2.5 Calculation of catches using actual estimates of abundance

The yield model calculates the "raw" catch corresponding to a given level of fishing intensity, in the wild and for caged animals. This catch depends on the estimated numbers in the population by size-class and the calculation accounts for the impact of grow-out of animals in cages under the assumption that all fish are exported at a given size (although allowance can be made for uncertainty in this size).

The "raw catch limit" corresponding to a given level of fishing mortality (in the wild), depends on the estimate of the current size-structure and abundance of the population and specifications for the remaining parameters of the yield model. It is calculated as the sum of the catch from fish in the wild and those in cages, i.e. $C^{\text{wild}} + C^{\text{cages}}$. The catch from the wild is estimated as the removals from the wild that are not caged, i.e.:

$$C^{\text{wild}} = \sum_l \frac{(1-\beta_l)\,S_l F^{\text{user}}}{M + S_l F^{\text{user}}} N^{l,\text{wild}} (1 - e^{-(M + S_l F^{\text{user}})}) \tag{19}$$

where $N^{l,\text{wild}}$ is the estimate of the number of animals in the wild by length-class, and
F^{user} is the user-specified level of fishing mortality.

The catch from caged animals cannot be computed using Equation 19 because there is no direct information on the total number and size-structure of Napoleon fish currently in cages. Therefore, the catch from caged animals is computed by first estimating the numbers (and size-structure) of the animals that would enter cages, $N^{l,\text{caged}}$, based on the estimated size-structure of the population in the wild and the level of fishing mortality, and then computing the catch corresponding to this size-structure by projecting it forward using Equation 1 until fish reach the size at which they are exported. $N^{l,\text{caged}}$ is given by:

$$N^{l,\text{caged}} = \frac{\beta_l\,S_l\,F^{\text{user}}}{M + S_l\,F^{\text{user}}} N^{l,\text{wild}} (1 - e^{-(M + S_l\,F^{\text{user}})}) \tag{20}$$

The number of fish exported legally is calculated as the "raw catch limit" less the number of fish consumed domestically. The estimated export quota has to be adjusted to account for two additional factors: the fraction of the catch that is exported illegally and is not reported (IUU) and the post-harvest mortality of live fish during transit from the site of capture or cages to exporting ports (PHM), i.e.:

$$C^{\text{export}} = (C^{\text{wild}} + C^{\text{cage}} - C^{\text{domestic}})(1 - IUU - PHM) \qquad (21)$$

where C^{export} is the export quota,
C^{wild} is the catch from the wild,
C^{cage} is the catch from caged animals, and
C^{domestic} is the domestic catch (the number of animals consumed domestically is calculated from the mass of animals consumed domestically under the assumption that the average mass of domestically consumed and exported fish is the same).

Currently, much (about 50 percent – China, Hong Kong SAR Agriculture, Conservation and Fisheries Department information, 2006/7, based on permit issuance) of the international trade in Napoleon fish that comes into China, Hong Kong SAR, is subsequently transhipped to Mainland China. An estimate of IUU trade could be made by subtracting the recorded exports from the source country from the recorded imports (by both sea and air) in China, Hong Kong SAR, and comparing these to the permitted quota. An example of this approach is provided in Appendix B. At present, there is no basis to estimate the mortality in transit from export to import ports, so the calculation of IUU trade in Appendix B is likely to be an underestimate. Likewise, there is no basis to estimate the post-harvest mortality (PHM). The calculations in Section 3.5 assume no PHM and therefore likely overestimate the actual sustainable export quota.

3. RESULTS

3.1 Parameterization of the yield model

3.1.1 Growth

Figure 6 shows the fit of the model to the age-length data. Results are shown separately for males and females. The data are pooled across age-classes in Figure 6 when sample sizes are low for improved visual assessment of the model fit. The model captures the central tendency of the length-at-age data, but it fails to account for what might be selectivity against young (<3-year-old) animals.

Table 4 lists the estimates of the parameters for the von Bertalanffy growth curve based on the standard maximum likelihood approach (i.e. minimizing the squares of the differences between the observed and model-predicted lengths) reported by Choat *et al.* (2006) and the estimates based on fitting to the data for the 189 individuals on which Figure 6 is based (assuming that the errors are normally distributed). Table 4 also lists the parameter estimates based on the fit of Equation 13. The value for σ (the extent of model / measurement error for the standard approach and the extent of process error for Equation 13) is assumed to be the same for males and females because likelihood ratio tests do not support sex-specific values for σ.

Table 4. Estimates of von Bertalanffy growth parameters (with associated standard errors, where available) based on standard maximum likelihood estimation and on the fit of model 13.

	Standard maximum likelihood		**Equation 13**
	Choat *et al*. (2006)	**This report**	
ℓ_∞ (females)	75.5 ± 17 cm	81.9 ± 2.4 cm	91.5 ± 3.4 cm
ℓ_∞ (males)	296.8 ± 2046 cm	185.4 ± 53.6 cm	168.4 ± 44.3 cm
κ (females)	Not reported	0.163 ± 0.010 cm^{-1}	0.131 ± 0.011
κ (males)	Not reported	0.0499 ± 0.021 cm^{-1}	0.0675 ± 0.039
σ	Not reported	128.8 cm	19.5 ± 2.31 cm

The estimates based on the revised data set do not differ significantly from those based on the data set used by Choat *et al*. (2006) although they are notably more precise. The estimates based on Equation

13 indicate larger asymptotic size for females and faster growth (lower ℓ_∞) for males. The estimates based on the standard maximum likelihood approach and those based on Equation 13 are not significantly different, although formal comparison of confidence intervals is somewhat questionable in this case because the standard maximum likelihood estimates and those based on Equation 13 are derived from the same age-length data pairs.

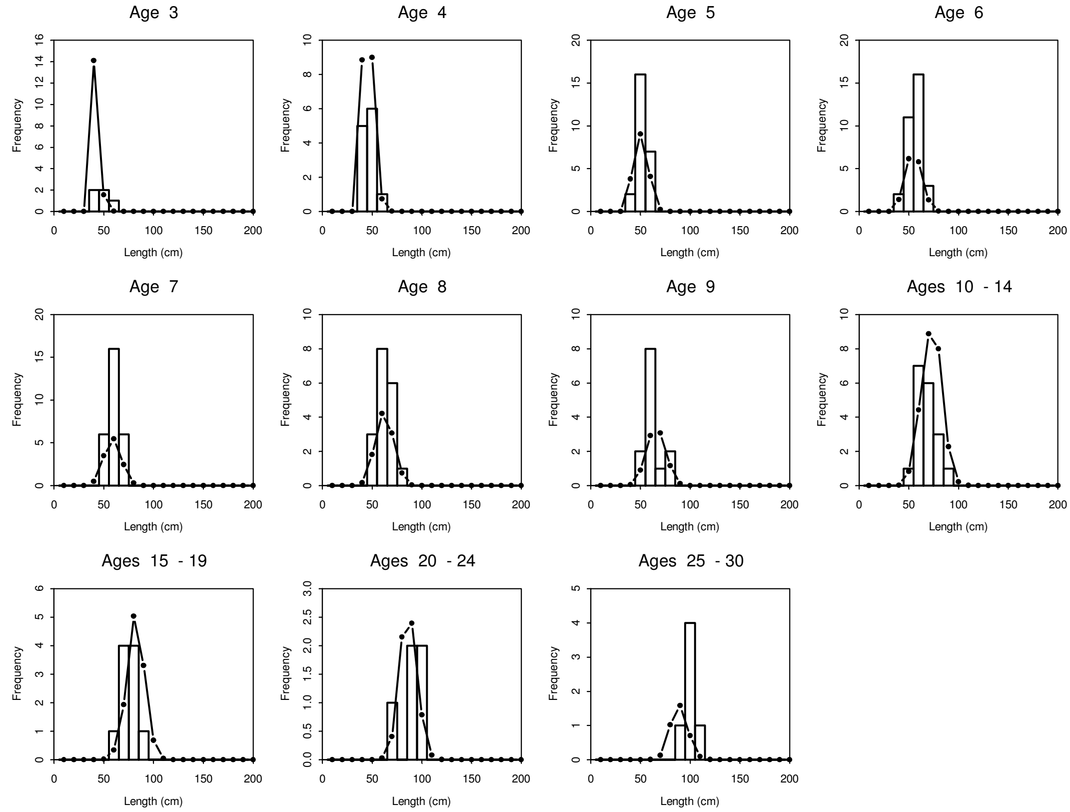


Figure 6(a). Fit of the growth model to the data for females.

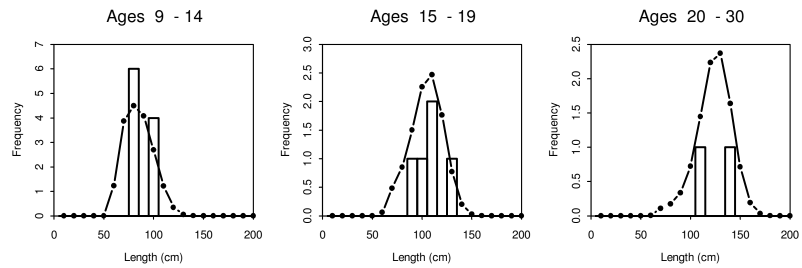


Figure 6 (b). Fit of the growth model to the data for males.

3.1.2 Natural mortality

Estimates of Z based on the data collected from the GBR, Australia, are reported in Figures 7 and 8. Results are shown for two values for the minimum number of data points for inclusion in the regression (1 or 2 data points) and whether the regression is restricted to data from reefs that are (currently) closed to fishing, (currently) open to fishing, or for all reefs. The estimate of Z from reefs closed to fishing is (not unexpectedly) lower than that for reefs open to fishing, but the estimate from the closed reefs alone is very imprecise (Table 5). The estimate of Z from reefs open to fishing is higher than for all reefs, suggesting that the M is somewhat lower than the estimate based on all reefs.

Given the imprecision of the estimate from closed reefs, however, the value of natural mortality used in the base-line analyses is set equal to the estimate from the entire data set (minimum of 2 points): 0.106 yr^{-1} (±0.022). This estimate will be positively biased to some extent because the estimate of *M* includes the impact of some fishing (on open reefs) as well as of natural mortality, so we used sensitivity tests to examine the implications of a lower value for *M* (see Section 3.4).

Table 5. Estimates of total mortality (*Z*, units yr^{-1}) with asymptotic standard errors, for reefs on the Great Barrier Reef that are known to be (currently) closed and open to fishing. Results are shown for analyses that restrict the minimum number of data points for each age to 1 and 2.

	Minimum number of data points per age	
	1	**2**
All data	0.113 (0.020)	0.106 (0.022)
Open reefs	0.117 (0.028)	0.140 (0.042)
Closed reefs	0.064 (0.030)	

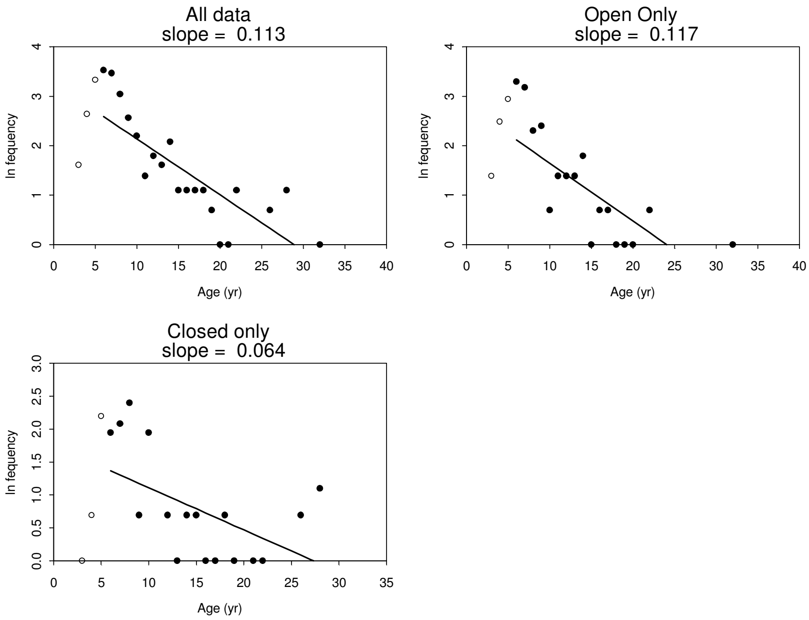


Figure 7. Regression of the logarithm of age-frequency on age. Results are shown for analyses based on all data, data for reefs open to fishing, and data for reefs closed to fishing. The analyses in this figure are based on all ages believed to be fully selected (closed circles); the open circles denote data for ages that do not appear to be fully selected.

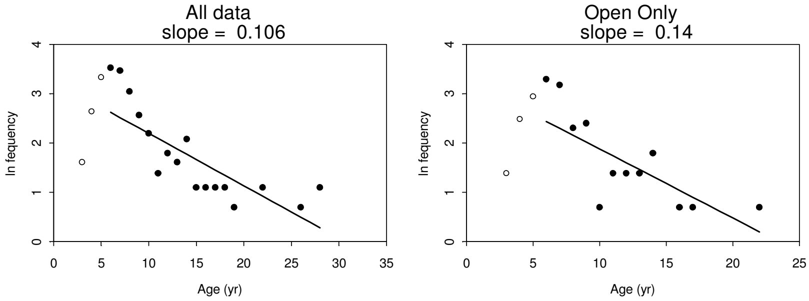


Figure 8. Regression of the logarithm of age-frequency on age. Results are shown for analyses based on all data, and data for reefs open to fishing. The analyses in this figure are restricted to ages for which the frequency is at least 2 animals for ages believed to be fully selected (closed circles); the open circles denote data for ages that do not appear to be fully selected.

The maximum recorded age for Napoleon fish is 32 yr, though the number of Napoleon fish that have been aged is very small and the largest fish available have not been aged. Accordingly, 32 yr is considered to be an unreliable estimate of the maximum age for this species. For the purposes of this report, therefore, the maximum age is set to 40 yr. A maximum age of 40 yr reflects a compromise between avoiding having too many animals reach the maximum age (1.4 percent of the population would reach age 40 for an M of 0.106 yr^{-1}) and the computational demands of the calculations.

3.1.3 Parameters related to maturity and egg production

Figure 9 plots the relationship between gonad weight and fork length obtained by Choat *et al.* (2006) (N=115). There is evidence for model-mis-specification in the fit to this data set (see the upper left panel of Figure 9). The poor fits appear to be due to attempting to fit a single gonad weight-length relationship to animals that are immature/resting as well as those that are ripe (Figure 9, lower panels). The lower panels of Figure 9 show the fits to the data for resting / immature animals and to the data for ripe animals separately. Given that the purpose of the gonad weight-length relationship is to quantify female reproductive output, the analyses of this report are based on the fit to the data for ripe animals only, i.e. $y = 12.81607\, e^{0.0025x}$, even though the sample size is fairly small (N=29).

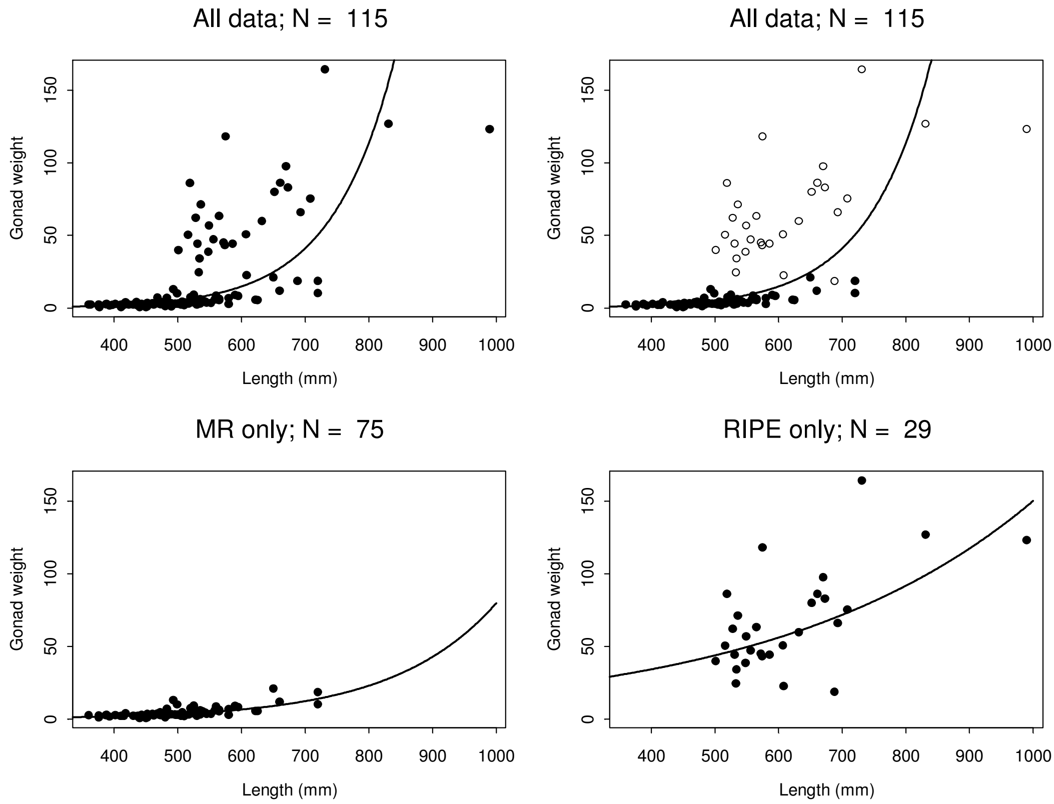


Figure 9. Gonad weight (grams) versus fork length. The upper panels show fits of the model $y = ae^{xb}$ to the entire data set. The open circles in the upper right panel are for animals designated to be "ripe" while the solid dots are for immature and mature but resting animals. The lower panels show separate fits to the gonad weight-length data for immature/resting animals and for ripe animals respectively.

Figure 10 summarizes data on maturity-at-length. The data for fish smaller than 35 cm were taken from Sadovy *et al.* (2003), while the data for larger fish were collected on surveys on the Great Barrier Reef (Bruce Mapstone, pers. commn). No fish smaller than 35 cm were found to be mature.

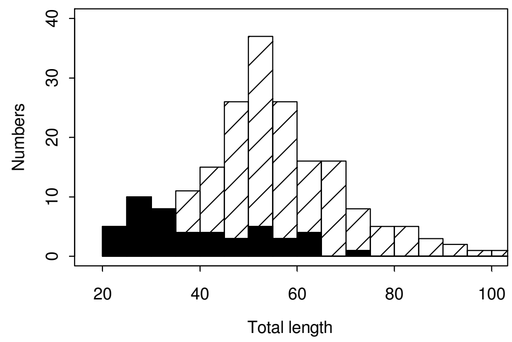


Figure 10. Data on maturity-at-length (Solid=immature; Dashed=active)

The curve fitted to the data in Figure 10 (Figure 11) is based on the assumption that maturity does not occur before 35 cm TL, that the size-at-50 percent maturity is 35 cm TL, and that maturity is a logistic function of length above 35 cm TL.

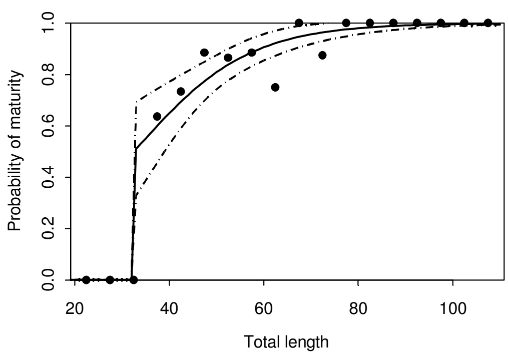


Figure 11. Maturity versus length (solid line) with asymptotic 95 percent confidence intervals (dashed lines).

3.1.4 Parameters related to density-dependence

Figure 12 plots the posterior distributions for steepness for each of the 12 stocks listed in Table A.1 (Appendix A), and Figure 13 plots the posterior distribution for steepness for an unknown stock. The posterior distribution for steepness can be summarized by a normal distribution for the logit of steepness ($\tilde{h}^k$) with mean 0.891 and standard deviation of 0.912.

The posterior distributions for steepness in Figure 12 for some of the stocks are centred about values that are lower than is the case for other teleost species (such as cods, herrings and haddocks) for which steepness is often estimated to be close to 1 (i.e. very little impact of a reduction in spawning biomass on recruitment; Punt, Smith and Koopman, 2005). This result is perhaps not unexpected given the perception that coral reef fishes tend to be less resilient to fishing than many other marine teleosts. It should, however, be noted that the posteriors for steepness in Figure 12 also generally assign low posterior probability to steepness values less than about 0.4.

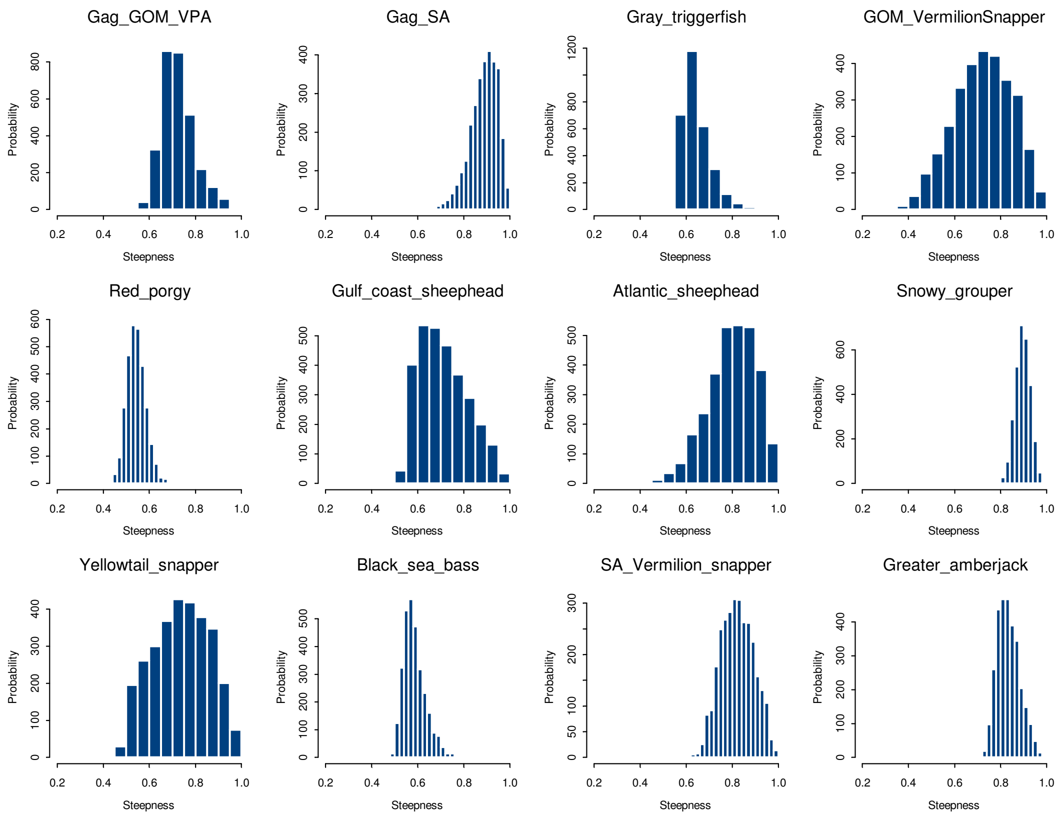


Figure 12. Posterior distributions for the steepness of the stock-recruitment relationship for the 12 stocks in Table A.1 (Appendix A).

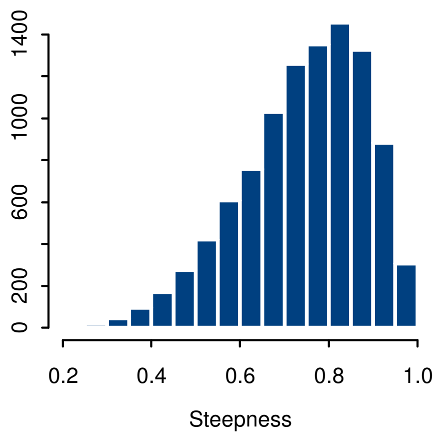


Figure 13. The probability distribution for the steepness of the stock-recruitment relationship for an unknown stock selected from a population of stocks characterized by those in Table A.1 (Appendix A).

Apart from steepness, the extent of density-dependence depends on the values for the parameters that determine the impact of changes in sex-ratio on fertilization rates. Since there are no data on the relationship between fertilization rates and sex-ratios for Napoleon fish, relevant data available for the related bluehead wrasse are used to provide the base-line value for the critical sex ratio (50) (Petersen *et al.*, 2001). The sensitivity of the results to this assumed value is examined in the tests of sensitivity (see Section 3.4).

3.1.5 Parameters related to grow-out

Results of interviews with collectors and traders about grow-out procedures are summarized in Appendix C (see also Sachoemar, Suharti and Sadovy, 2006). All Napoleon fish were wild-caught and the size of first capture varied. It takes 14 days to several years to grow-out the species in net cages to a size suitable for export, with this time depending on the size at first capture. All Napoleon fish in grow-out facilities where interviews were conducted were intended for export, mainly to the China, Hong Kong SAR, market. An estimate of grow-out mortality was determined by a weighted sum of the mortality rates by collector (range 0-80 percent over periods in cages ranging from 1 to 48 months), weighting the mortality rate (expressed as an annual rate) by the number of fish collected. The resulting estimate of the annual mortality rate in cages is 0.134 yr^{-1} (bootstrap SD = 0.064 yr^{-1}). The sizes of animals received for grow out ranged from 5-30 cm. Note that some of the input sizes had to be inferred from the input masses and, where data were expressed as a range, the midpoint was used. Weighting, by the number collected, the input sizes for the 21 collectors who provided information on input size and numbers collected, the size-structure of animals selected for grow-out was:

0-10 cm	10-20 cm	20-30 cm	30 cm+
0.615	0.096	0.275	0.013

These data cannot be used directly in the model, but form the basis for the assumption that animals smaller than 25 cm are sent to cages rather than being exported, i.e. that $\beta_l = 1$ (Equation 1) for fish of length 25 cm and lower, and 0 above this length. The growth rate in cages is assumed to be the same as that in the wild (see Section 3.1.1), given the lack of data on growth rates in cages.

3.1.6 Parameters related to selectivity

There are several ways to define the population length-frequency used to calculate the empirical measures of selectivity. The first is to weight the length-frequencies in each fishing intensity class by the relative density in that fishing intensity class ("Weight by density"). A second approach (given the paucity of data) is to pool the length-frequencies by fishing intensity class, giving the data for each fishing intensity class equal weight ("Equal weight"). A third approach is to recognize that fishing occurs mainly on "high" and "medium" fishing intensity areas so accounting for the length-frequency of "low" fishing intensity areas when defining the population length-frequency may be invalid ("Weight by density (ignore low fishing intensity)").

Figure 14 shows the fit of the selectivity model to the three selectivity patterns inferred from the data on animals in the China, Hong Kong SAR, market and the three ways to define population length-frequency. When given equal weight, the survey data suggest that small animals are not selected for capture. This is not very realistic because it effectively precludes the catch of animals for grow-out. The two selectivity curves based on weighting the data by density lead to fairly realistic selectivity patterns (although the fits are not particularly good). The analyses in this report are based on weighting the length-frequency data by density, but ignoring the data for "low" fishing intensity areas because few catches would be coming from areas of "low" fishing intensity.

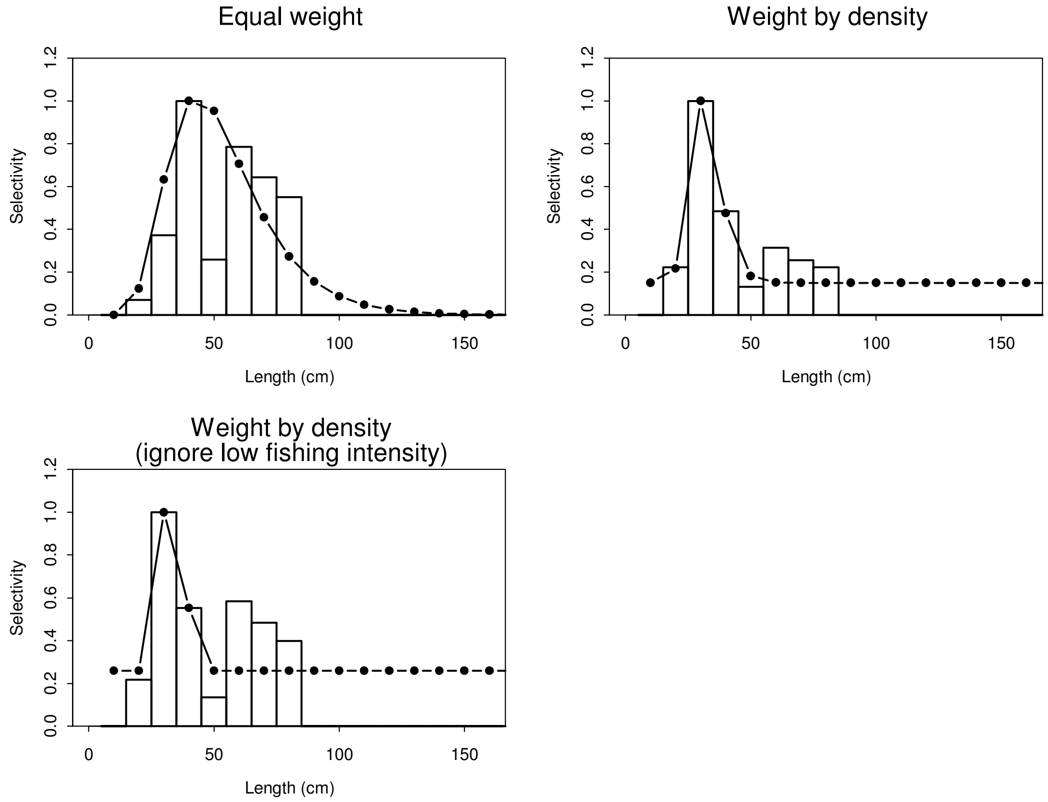


Figure 14. Observed selectivities by length (bars - catch recorded in China, Hong Kong SAR, markets divided by UVS-estimated abundance; Sadovy unpublished data, Sadovy et al., 2003; Sadovy, 2005) and the values predicted by the selectivity model listed in the text (lines)

The results in Figure 14 should be interpreted with some caution because: a) the catches in China, Hong Kong SAR, include (an unknown proportion of) fish that are "grown out"; inclusion of such fish in the analysis will bias the selection curve to the right; and b) there might be some selectivity of the UVS technique for the smaller fishes (possibly those below about 10-15 cm, and increasingly for progressively smaller fish which can be quite shy). These two sources of bias will tend to balance each other out to some extent, but, in the absence of additional data, it is not possible to determine the net effects of these two sources of opposite bias.

3.2 Model validation

No attempt can be made at present to validate the yield model against independently collected field data. This is because, given the few data for Napoleon fish, most of the available data are being used to specify the best estimates for the parameters of the model. However, it is possible assess the validity of the model to some extent by qualitatively evaluating the model outputs based on expert judgement. In addition, the utility of the model, and the importance of accurately and precisely determining the values for its parameters, can be assessed by conducting sensitivity tests in which some of the specifications of the model are changed. The results of such sensitivity tests (see Section 3.4) could be used to inform priorities for additional data collection.

Figure 15 compares the length-frequency distributions for the exported catch (i.e. the catch in the wild plus the animals that were "grown-out" and exported later) for a set of base-line specifications (see Table 1) and for various choices for the rate of fishing mortality. As expected, increasing the level of fishing mortality from a value close to 0 leads to a truncation of the length-frequency of the exported catch around the length at modal selectivity (34 cm).

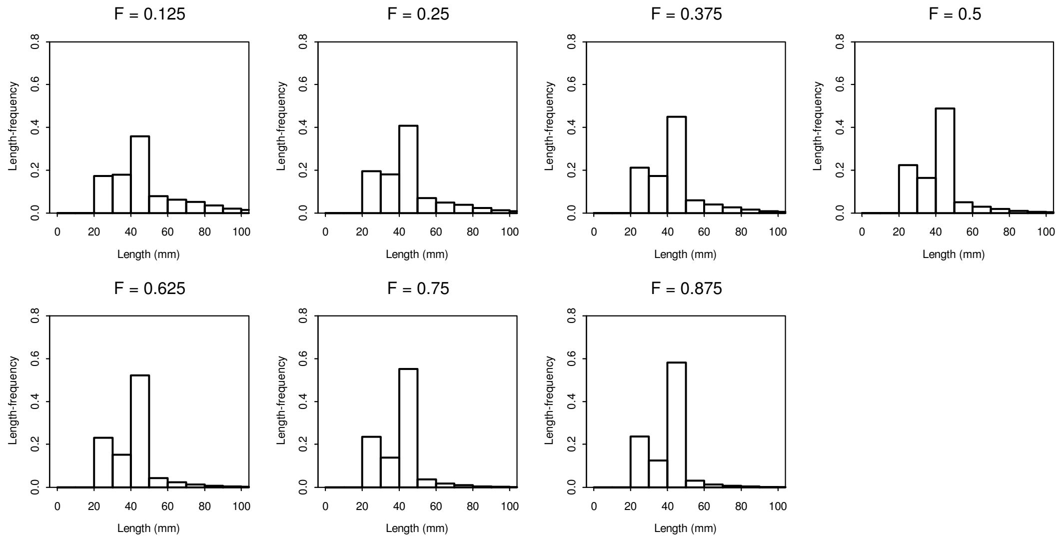


Figure 15. Base-line model-predicted catch length-frequency distributions for different levels of fishing mortality.

Figure 16 explores the base-line model further by plotting the "raw catch limit" (in weight and in number), the biomass of spawning females relative to its unfished level, and the sex-ratio (mature females per mature male) against fishing mortality. The base-line model suggests that the population is female-biased even in the absence of exploitation and that the extent to which the population is female-biased will increase with increasing levels of fishing intensity (as would be expected for a protogynous hermaphrodite in which the rate of sex-change is assumed to be density-independent[4]). The absolute level of the sex-ratio is, however, fairly uncertain, primarily because of uncertainty associated with the value of the parameter governing the rate of sex-change.

The fishing mortality at which the expected exported catch is maximized, F_{MSY}, differs depending on whether catch is recorded in mass or in numbers; it is higher when catch is measured in numbers. More importantly perhaps, F_{MSY} based on the median relationship between catch and fishing mortality would, with a high probability, lead to collapse of the resource. This arises because of the uncertainty associated with the parameters of the model, particularly the steepness of the stock-recruitment relationship. The relationship between the reduction in female spawning biomass and fishing mortality is relatively more precise than the other relationships in Figure 16. Precision becomes increasingly poor, however, as fishing mortality is increased. The relative lack of precision in all but the lower right panel of Figure 16 is one reason that some fisheries management jurisdictions have based their fishing mortality targets and thresholds on the relationship between fishing mortality and reduction in spawning biomass (or spawning biomass-per-recruit) rather than on relationships that depend on estimates of the steepness of the stock-recruitment relationship (e.g. Anon, 1998; 2005).

[4] This assumption forms the basis for several models for protogynous hermaphrodites (e.g. Punt, Garratt and Govender, 1993; Little *et al.,* in press).

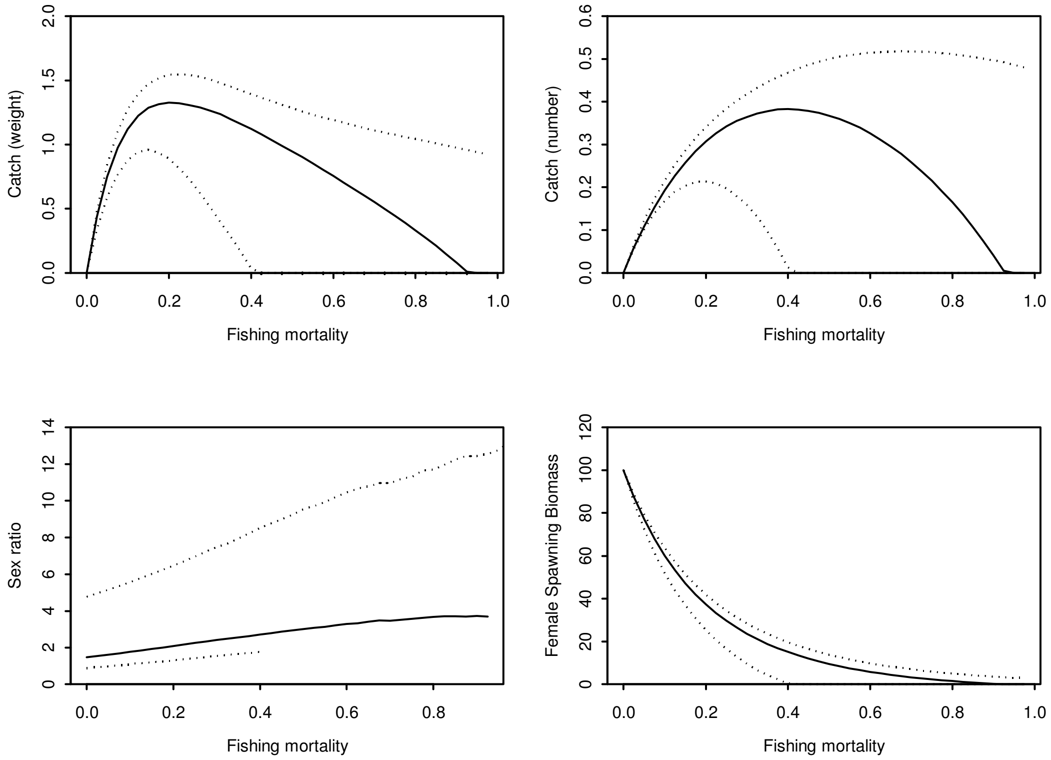


Figure 16. Key diagnostic plots for the base-line analysis. The solid lines are medians and the dotted lines 95 percent intervals.

Figure 17 shows the predicted length-frequency distribution for the export catch based on the actual length-frequency data. Although this distribution has its mode at lengths consistent with the known size-frequency of imports into China, Hong Kong SAR, Figure 17 indicates that a higher fraction of large fish is predicted by the model to be exported than is observed. This result arises because the model assumes that areas associated with all three levels of fishing intensity (including "low" fishing intensity areas) will be harvested. As shown in Section 3.3, areas of "low" fishing intensity include some fairly large animals.

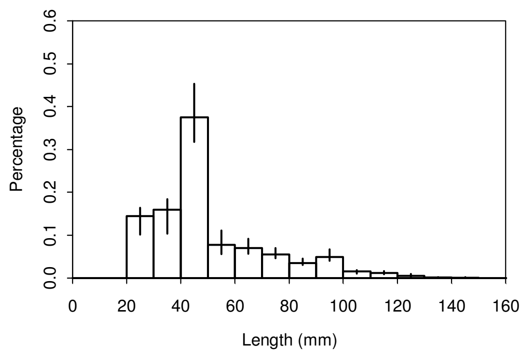


Figure 17. Predicted export length-frequency for Napoleon fish.

3.3 Abundance estimation

Figure 18 compares the length-frequencies by fishing intensity class based on data from Indonesia and based on data from the SE Pacific (Michel Kulbicki, pers. comm.). The length-frequency distributions for Indonesia and the SE Pacific are similar when the data collected from areas of "low" fishing intensity are analysed. It is, however, hard to make conclusive statements for the other two levels of fishing intensity owing to the small sample sizes (particularly for the areas of "high" fishing intensity).

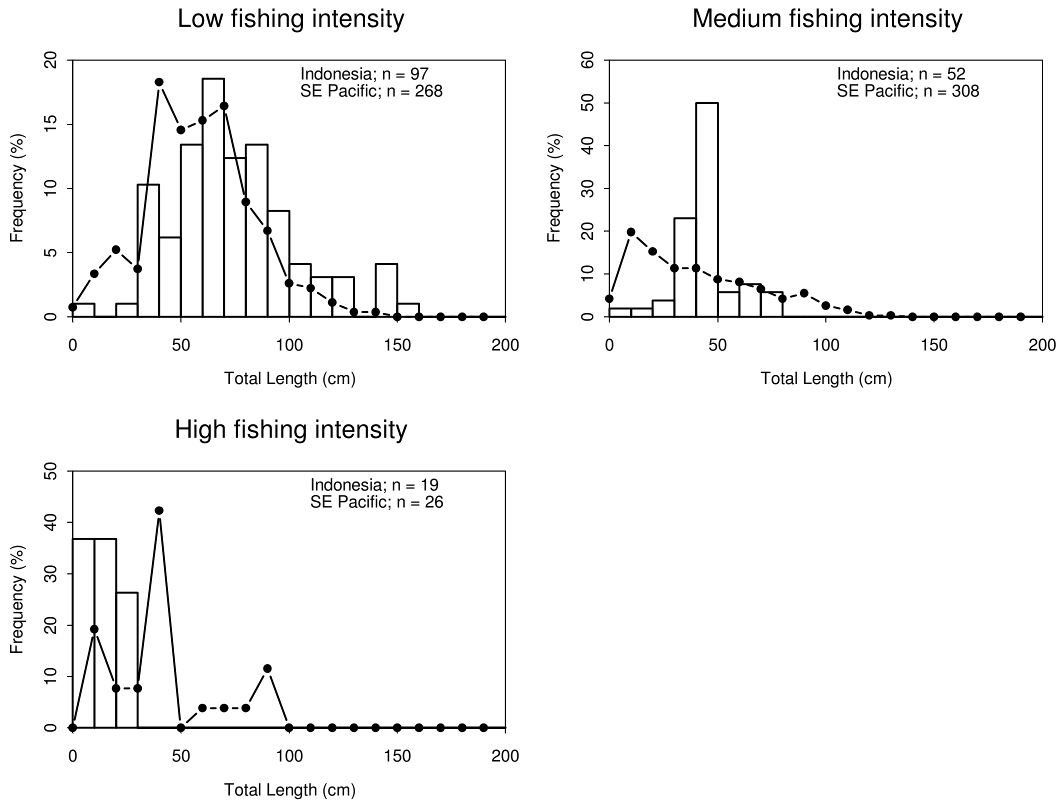


Figure 18. Population length-frequencies based on data collected during surveys in Indonesia (bars) and population length-frequencies based on data collected in the South Pacific (dots) (source of South Pacific data, Michel Kulbicki).

According to Reefs At Risk (Spalding, Ravilious and Green, 2001), 82 percent of Indonesia's reefs are in poor condition, so the use of a lower estimate of suitable available reef than 100 percent would be more appropriate to take account of this i.e. although 82 percent of reef is in poor condition, the Napoleon fish is likely to be able to occupy sub-optimal reef condition, we therefore apply a value of 50 percent of total available reef area (rather than 82 percent) as being unsuitable for Napoleon fish. [While adult Napoleon fish do not appear to have a heavy dependence on high live coral cover, small juveniles appear to be particularly abundant in areas of high live coral cover, so the condition of coral cover may be an important factor in determining fish numbers in some areas]. Using 50 percent of the total reef area of 51 020 square km in Indonesia (Spalding, Ravilious and Green, 2001) as our estimate of reef area that could be used by adult and large sub-adult Napoleon fish is therefore generous. We recognise, however, that this aspect of the analysis will need sensitivity work in addition to new data we will collect in the field, and is also pending finer scale analyses of reef area based on satellite imagery which is anticipated to substantially reduce the estimate of the habitat area of Napoleon fish in Indonesia. Table 6 expresses the total area in terms of the percentage by fishing intensity class. The data in Table 6 are based on opinions expressed in discussions with several staff of LIPI and Agency for the Assessment and Application of Technology (BPPT)-government divisions in Indonesia to Y. Sadovy.

Table 6. The percentage of the total area (51 020 square km; Spalding, Ravilious and Green, 2001; http://coral.unep.ch/atlaspr.htm) associated with each level of fishing intensity according to consultations with staff of government divisions of Indonesia.

	Fishing intensity	
High	**Medium**	**Low**
70%	25%	5%

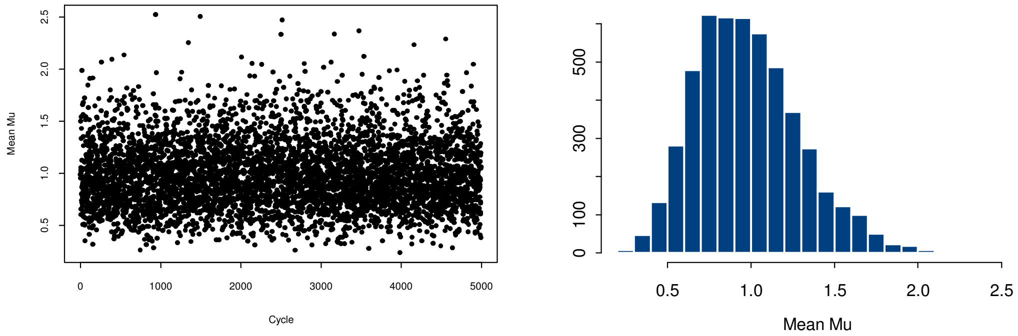
Figure 19 shows the posterior distributions for the mean density by fishing intensity class. This figure also shows the traces of the samples obtained from the Markov Chain Monte Carlo (MCMC) algorithm. These posteriors can be summarized by normal distributions with means (standard deviations) given by 0.982 (0.316), 0.556 (0.332), and 0.0921 (0.0507) fish per 10 000 m^2 for "low", "medium" and "high" fishing intensity respectively.

Estimates of density based on UVS data from the SE Pacific were compared to the corresponding estimates based on surveys in Indonesia to ascertain whether the trends in density between areas with "low", "medium" and "high" fishing intensity are consistent across regions. It would not be expected that the absolute densities would be necessarily the same across regions. The posterior distributions for density (numbers per 10 000m^2) for "low", "medium" and "high" fishing intensity in the SE Pacific were 4.59 (0.568), 2.67 (0.326), and 0.394 (0.176) respectively. Table 7 expresses the posterior mean densities in the "medium" and "high" fishing intensity areas relative to that for the "low" fishing intensity areas. The results in Table 7 suggest that there is fairly remarkable consistency in relative densities among "low", "medium" and "high" fishing intensity areas in these two regions even though the absolute densities between Indonesia and the SE Pacific differ.

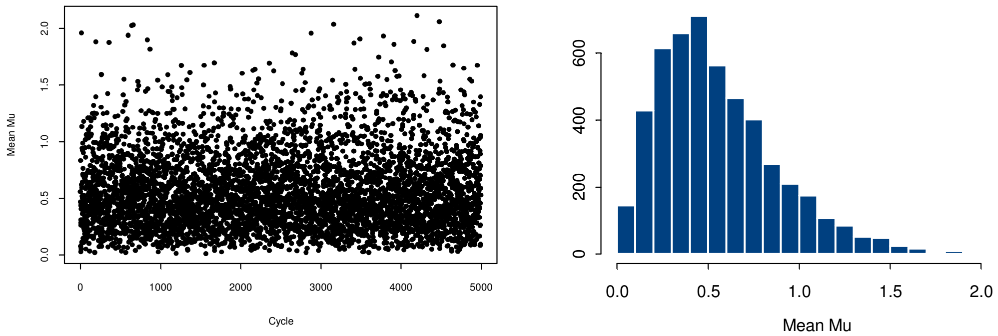
Table 7. Densities in the "medium" and "high" fishing intensity areas relative to those in the "low" fishing intensity areas based on the application of the Bayesian hierarchical model to data collected from Indonesia and the SE Pacific (see above for estimates of absolute densities).

Fishing intensity	**Indonesia**	**SE Pacific**
Medium	0.566	0.582
High	0.094	0.086

(a) "Low" fishing intensity



(b) "Medium" fishing intensity



(c) "High" fishing intensity

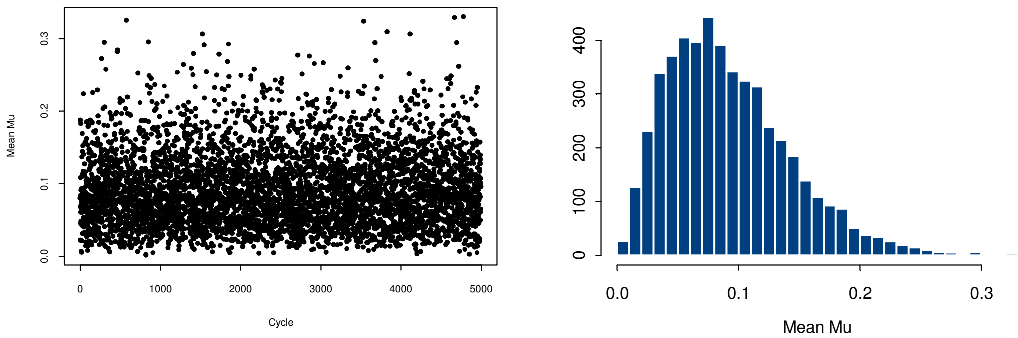


Figure 19. Posterior distributions for the mean density (Mu, in number of fish per 10 000 m^2) among sites and the traces of the samples from the MCMC algorithm. Results are shown for "low" (a), "medium" (b) and "high" (c) levels of fishing intensity.

3.4 Sensitivity analyses

Figure 20 explores the sensitivity of the "best" estimates and 95 percent intervals for four potential management reference points: i) F_{MSY} (in numbers), ii) F_{MSY} (in weight), iii) the fishing mortality at which the sex-ratio of mature animals is twice that in a virgin state ($F_{F:M}$), and iv) the fishing mortality at which the female spawning biomass is 20 percent of its virgin level, $F_{20\%}$ ("F_{20}" in Figure 20). F_{MSY} and $F_{20\%}$ were chosen as the focus for this examination of sensitivity because they represent typical fisheries management reference points while $F_{F:M}$ provides a reference point that is applicable directly to one of the concerns associated with fishing a protogynous hermaphrodite, namely a marked increase in the imbalance of the sex ratio (numbers of females per male) of the spawners. All of the results are based on 1000 simulations in which F was increased from 0 to 1 yr^{-1} in steps of 0.02 yr^{-1}.

Results are shown in Figure 20 for ten sensitivity tests in addition to those for the base-line set of specifications:

a) Natural mortality is normally distributed with a mean of 0.106 yr^{-1} and a standard deviation of 0.022 yr^{-1} (see Table 2).
b) The maximum age considered in the model is reduced from 40 yr to 30 yr.
c) The maximum age considered in the model is increased from 40 yr to 50 yr.
d) Steepness (h) is set to 0.75.
e) Steepness (h) is set to 0.6.
f) The parameter that determines the impact of sex-ratio on fertilization rate (q) is increased from 0 to 0.1.
g) Natural mortality for fish in cages is increased from 0.134 yr^{-1} to 0.2 yr^{-1}.
h) The highest length at which fish are sent to cages is increased from 25 cm to 35 cm.
i) Natural mortality is assumed to be 0.08 yr^{-1}.
j) The parameter that determines the impact of sex-ratio on fertilization rate (q) is increased from 0 to 0.1 and the critical sex-ratio (χ_c) is reduced from 50 to 20.

The results are, in general, fairly insensitive to the changes examined, but that may be because the results are fairly imprecise even for the base-line specifications. As expected, setting h to a lower value than implied by the distribution in Figure 13 generally leads to lower estimates of the fishing mortality reference points. The marked reduction in the widths of the 95 percent intervals for three of the four reference points for the sensitivity tests in which steepness is pre-specified instead of being assigned a distribution (sensitivity tests "d" and "e" in Figure 20) suggests that steepness is the major source of uncertainty for these reference points. The value of $F_{F:M}$ is not sensitive to steepness. Rather, this quantity is sensitive to uncertainty regarding M and the value assumed for the maximum age. Lowering the value assumed for M (sensitivity test "i") leads to lower values for all of the reference points. The results are insensitive to the specifications related to the impact of sex-ratio on fertilization rates (sensitivity tests "f" and "j") because the sex-ratio never reaches the level at which this impact begins to occur before the population is predicted to collapse anyway (see Figure 16).

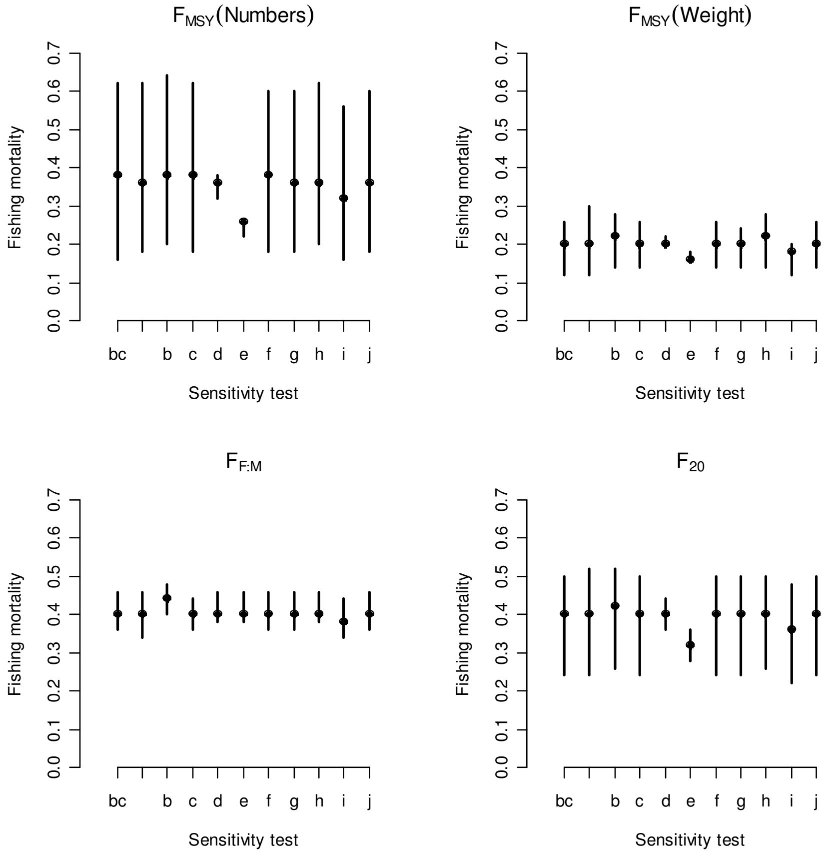


Figure 20. Fishing mortality (best estimates and 95 percent intervals) corresponding to four management reference points for the base-line set of specifications (bc) and ten alternative sets of specifications (see above for the specifications for sensitivity tests a-j).

3.5 Preliminary estimates of sustainable export quota

A sustainable export quota of Napoleon fish for Indonesia was estimated assuming:

1) an optimal fishing mortality rate of 0.2 $year^{-1}$, which is approximately the most conservative fishing mortality rate among the tested reference points (see Figure 20);
2) 100 tonnes of fish are used for domestic consumption (FAO figures supplied by Indonesia for 2005; Appendix B); and
3) 46 percent of the total catch is IUU (Appendix B).

The "best estimate" of the total production is 38 146 fish (fish exported directly from the wild and those exported following grow-out) of which 8 907 could form an export quota (Table 8). The difference between 38 146 and 8 907 reflects the impact of the assumed 100 mt domestic catch and the IUU fraction of 46 percent. However, these estimates are highly uncertain and the strict application of a precautionary approach, i.e., basing the export quota on a lower percentile of the probability distribution, could mean a zero export quota for Indonesia. A zero export quota indicates that, under the current conditions, there is a non-negligible probability that the level of reported domestic consumption (100 tonnes) is already higher than the production the stock could sustain. These preliminary results demonstrate the importance of giving appropriate consideration to the level of domestic consumption (and illegal fishing) in the sustainable management of fisheries for the Napoleon fish. In this particular case, the setting of any non-detriment export quota should hinge on evidence that efforts are being made to effectively manage the domestic fisheries and control the illegal exports, which are currently responsible for the largest share of the removals. The estimates (and Monte Carlo intervals) are highly sensitive to the habitat area suitable for the species, which further highlights the need for more accurate estimates of reef areas in Indonesia including an indication of suitable habitat for Napoleon fish.

Table 8. Preliminary estimates of export quota (in numbers) for Napoleon fish in Indonesia. The point estimates are the medians over Monte Carlo replicates and the numbers in parenthesis are 95 percent intervals. Estimates are based on a fishing mortality rate of 0.2 year^{-1}, on a domestic consumption of 100 tonnes, and on an estimated percentage of IUU exports of 46 percent. The export quota is calculated as the difference between the estimated total production (wild + grow out) and the domestic catch, corrected for the estimated IUU exports (see Equation 21).

	Total production	**Total wild catch not sent to cages**	**Production from grow-out**	**Export quota**
Catch (number)	38 146 (18 428 – 63 530)	30 147 (14 824 – 49 773)	8 056 (3 357 – 13 711)	8 907 (0 – 21 987)

4. DISCUSSION

4.1 Limitations and recommendations for improving the approach

The limitations of the model can be divided into those related to a lack of understanding of the population dynamics and fisheries for Napoleon fish and the lack of data to parameterize models. Examples of the former relate to the fact that the model applies to a single homogenous population when, if fact, Napoleon fish exist as a meta-population. Similarly, the impact of an unbalanced sex ratio caused by fishing and very low densities in some areas cannot be modelled owing to lack of information, even for other species. Only in a very few cases (e.g. Little *et al*., in press) have attempts been made to develop models at the most appropriate temporal and spatial scales for coral reef species and fisheries. At present, however, these models are not easily used for quota setting, particularly in data poor situations.

Data have been aggregated over a wide geographic area (Indonesia, Australia, Pacific, etc.) to estimate the values for the parameters of the yield model, primarily because of the general lack of samples for Napoleon fish. Although there is no evidence to suggest, for example, that the maturity and growth for Napoleon fish differs spatially, the power of any statistical tests to detect spatial differences in the values for biological parameters is currently low. Where possible, the analyses are based on data collected from Indonesia, but the lack of data on age, growth and maturity for Indonesia meant that data for Indonesia had to be augmented by data from Australia when estimating growth curves, natural mortality and the relationship between maturity and length.

The results of the yield model depend critically on assumptions regarding density-dependence. In particular, estimates of quantities such as F_{MSY} are very sensitive to the value assumed for the steepness of the stock-recruitment relationship. Figures 12 and 13 are based on data for coral reef fishes, but there is a lack of consistency in how spawning biomass is calculated in stock assessments for these fishes (males and females, females only, etc.). Therefore, while the distribution for steepness in Figure 13 is used for the analyses, it is probably subject to considerable uncertainty.

The live reef fish trade presents several challenges for achieving an estimate of sustainable use. In particular, and in addition to the development of a stock assessment model, there are other considerations relevant to fisheries that must be factored into discussions on sustainable use. Important amongst these are the extent of IUU export out of source countries, and the mortalities of fish (because this is a trade in live animals) during transit from points of capture to export loading sites. Since these figures are not reflected in export figures from source countries and are believed to be considerable, every effort must be made to produce estimates since the removal of these animals must be included into total annual catch for sustainable use to be determined for NDF. In order to obtain import data in China, Hong Kong SAR, improved communication with the government Agriculture Conservation and Fisheries Department CITES office is necessary.

Other high-priority data needs are:

1. Additional information on the sizes of fish caught in the wild, the fraction of these exported immediately, and the fraction that are grown out in cages.

2. Additional information on the sizes of fish that are entered into cages and the size to which caged fish are grown-out before being exported.
3. Any data not already included in the model (e.g. sex-ratios by age/ length in highly fished and unfished areas) and which could be used for model validation purposes. In particular, if catch length-frequency data were available spatially, they could be used to validate the model's predictions of catch length-frequencies.
4. Better estimation of reef area in Indonesia suitable for the Napoleon fish.
5. Information on the selectivity pattern for UVS.
6. Estimates of the mortality between capture and cage-culture, during cage culture, and during transit operations both prior to export and after export but prior to import.
7. Improved estimates of the percentage of reef under different levels of fishing intensity.
8. Additional estimates of density from UVS (particularly for areas of "high" and "medium" fishing intensity).

4.2 Use of the model as part of a management system

The approach outlined above was developed with the objective of assisting exporting countries in the evaluation of sustainable export quotas for Napoleon fish based on the best available information about the species and local fisheries. In this case, the source country was Indonesia, but the model can be adapted for other countries. The tool attempts to support decision making in the establishment of catch quotas, which is a challenging task because of the difficulty in defining with precision what the abundance of the stock and the actual catches are. Also, information on domestic use and IUU volumes is also needed. The latter, in particular, can be challenging to estimate. The task is even more challenging in situations of scarce catch, transport and market data and limited enforcement, such as is faced by Indonesia. Despite these uncertainties, the approach does provide a scientific basis for defining a reference value for the export quota, a CITES requirement that until now has been done in a rather ad hoc manner by Indonesia for the case of Napoleon fish.

The approach presented should not be viewed as an exclusive management decision tool. Instead, it should be used as part of an adaptive management cycle, involving the monitoring of indicators about the status of the resource and the regular review of the effectiveness of fishing controls and management decisions, including the setting of export quotas, effort limits, size limits, protected areas, and the banning of destructive fishing gears (e.g. cyanide fishing). Moreover, any quotas assigned are only as useful as the enforcement applied to ensure compliance with them. Careful consideration is needed to ensure enforcement of export quotas which may require strict control measures, such as allowing air-only exports, to ensure implementation. The active role of importing countries is also extremely important for successful enforcement.

The monitoring of resource status is an important source of feedback in the adaptive management cycle that needs particular attention in the case of Napoleon fish. Resource monitoring is still limited by the lack of suitable biological indicators, i.e., indicators that are cost-effective, in the sense that they could be calculated on an annual basis, and adequate for data-limited situations. Although UVS data may provide a reliable indicator of fish densities, high cost makes it prohibitive for most range States to conduct UVS on an annual basis. Thus, if regular UVSs are necessary to establish the basis for setting and adjusting export quotas, but can be done only (say) every 5 years. Alternative, fishery-dependent indicators should also be available for the continuous monitoring of the status of the resource. Enforcement effectiveness must also be assessed both within and between countries.

The repetition of the adaptive management cycle through time should also allow for the analysis tool and biological reference points to be updated as new data become available. Data from areas that have been effectively closed to fishing and where the species has been allowed to recover would be particularly relevant for improving the representation of density-dependent processes, such as the steepness of the stock recruitment relationship, to which the results of the model are highly sensitive.

4.3 Current and recommended conservation measures for the Napoleon fish in Indonesia

Indonesia has been the major exporter of Napoleon fish to China, Hong Kong SAR, for many years and is hence the major exporter of the species globally. Interviews with fishers, traders, biologists and government officials clearly indicate that catch rates and volumes, as well as fish sizes, have generally declined over the last decade or so. As a result, traders are continually seeking new fishing grounds for the species. Large fishes are far less common than they once were, and small fishes (well below the size of sexual maturation) are regularly caught and grown-out in net cages prior to export: this is significant inasmuch as these fish do not have the opportunity to reproduce, removing potential adults from local populations (Sadovy *et al.*, 2003).

In addition to the CITES Appendix II listing of 2004 which calls for all exports of Napoleon fish to be based on a sustainable fisheries plan, there are domestic regulations that address the size at which fish may be caught (with the appropriate permits) and exported, who can catch and export them, and the method of catching (Sadovy, 2006). Fish below 1 kg and above 3 kg cannot be exported and all fish must be caught with traditional fishing gears; the widespread use of cyanide is illegal. If fish below 1 kg are caught, they can legally be placed in floating net cages and grown to a size larger than 1 kg and then exported. However, there appears to be no enforcement of this regulation and many fish below 1 kg are exported. Relatively few fish of > 3kg are exported and interviews with culturists indicate that grow-out to > 3 kg is not common. The species also finds some protection in marine parks, but only where fishing is not permitted and the regulations are enforced. There are seven marine protected areas in Indonesia (Takabonerate, Kepulauan Seribu, Karimun Jawa, Wakatobi, Teluk Cendrawasih, and Togian MPA) and more are planned. Each MPA is authorized by the Balai Taman Nasional Laut (National Park Office) (Faustina Ida Hardjanti, PHKA pers. comm.). Emphasis on enforcement in these protected areas is low, however, and needs to be improved, in particular where reproductive groups of Napoleon fish apparently persist. Some protection is conferred in a few *de facto* "reserves" comprised of areas difficult to access or hard or unattractive to fish.

In 2006, a preliminary CITES-related quota of 8 000 fish for export was introduced, based on trader/export information subject to further information becoming available – there was no consideration of other uses of the species (e.g. domestic or illegal catch) in setting the quota. The 2006 quota was retained for 2007, in part following the outcomes of the present work (S. Suharti, pers. comm.). In addition, only air shipments are recommended by the Scientific Authority, to better control exports (S. Suharti, pers. comm.).

Export quotas are the control measure of choice for the Management and Scientific Authority because Indonesia covers a vast geographic area which would require a large amount of resources to enforce otherwise. A new quota is set every year, usually at the end of the year to take effect the following year. The quota is assigned by the Director of Biodiversity Conservation, Forestry Department and delivered through the Regional Office for the Conservation of Natural Resources (BKSDA, Conservation Unit Office) in all provinces and districts, from where it is distributed to traders/exporters. In accordance with the Decree of the Minister of Forestry No. 447 of 2003 the BKSDA office issues permits to catch Napoleon fish in the field based on the quota allocated for each province. The provincial offices of the Management Authority (BKSDA) control and enforce catch and collection permits, and implement quota management and monitoring for CITES-listed species in their administrative jurisdictions.

For domestic transport, the specimens must be covered by permits issued by BKSDA or its Section Offices. Permits for domestic transport are issued in accordance with the annual quota and with reference to catch permits. The domestic transport permit, started from January 2005, is now standardized throughout Indonesia to facilitate better control. All permits (collection and domestic transport permits) are recorded and then reported to the Management Authority, which is expected to improve monitoring of internal (domestic) trade.

Napoleon fish collectors and exporters must be licensed and registered at the Directorate General of Forest Protection and Nature Conservation in order to apply for CITES export permits. All shipments are verified and checked by the provincial office of PHKA (BKSDA) and officers are posted in the designated international ports. Any violation of this regulation is sanctioned based on the provisions of the Government Regulation No. 8 of 1999 concerning Wild Animals and Plants Species Utilization, which implements Act No. 5 of 1990 concerning Conservation of Biological Resources and Their Ecosystems. The Government Regulation No. 8 of 1999 provides penalties for smuggling or false declarations or trade that is not in accordance with the provision of the regulation and violators may be liable to imprisonment (in accordance with the Customs and Excise Law) (Faustina Ida Hardjanti, DKP, pers. comm.).

While it seems evident that the listing of Napoleon fish in CITES Appendix II has resulted in improvements in the control of fisheries for the international trade, there are justified concerns that the existing management and enforcement measures are not sufficient to regulate the domestic use to more sustainable levels. Controlling domestic use would involve some difficult facets, such as setting limits to the number of fishing permits, which would require further consideration about issues of use and access rights to fishing. Where domestic consumption is linked to traditional use with cultural significance, it will be important to consider awareness raising and environmental education programmes as supplementary activities to fisheries management. Measures such as bag limits (i.e. establishing a limit for number of fish allowed per fisher per day) could also play a role to limit the amount of fish taken for domestic use.

Compliance is a key factor for successful application of any management measures. It is compounded by the feasibility and legitimacy of the regulations in place and also by the capacity to enforce these regulations. Enforcement of regulations is obviously an important limitation in a country as vast as Indonesia and for the type of small-scale fisheries targeting Napoleon fish. Experiences in other coastal fisheries in the Asia-Pacific region indicate that the solution to the problems of unsustainable use and limited capacity to manage fisheries often involve building more participatory types of fisheries management (e.g. community-based management, co-management), where fishing communities have well defined rights to use the resources and are also fully involved in the process of regulation, monitoring and enforcement of the agreed rules (Pomeroy, 1995; Brown, Staples and Funge-Smith, 2005; Pomeroy and Rivera-Guieb, 2006). Key to the success of these systems is that they have the right incentives (economic, socio-cultural, etc.) for people to cooperate and comply. Several such experiences exist in Indonesia, based on both traditional (or customary) community-based fisheries management systems ("sasi laut"; Harkes, 1999) or resulting from recent government incentives for decentralization through fisheries co-management (Bachtiar, 2000; Nikijuluw, unpub.). The results from these experiences may show promising ways forward to improve fisheries management of threatened species such as the Napoleon fish.

5. REFERENCES

Andrefouet, S., Muller-Karger, F.E., Robinson, J.A., Kranenburg, C.J., Torres-Pulliza, D., Spraggini, S.A. & Murch, B. 2005. Global assessment of modern coral reef extent and diversity for regional science and management applications: a view from space. International Coral Reef Symposium Proceedings 2005. 14 pp.

Anon. 1998. Final Environmental Assessment/Regulatory Impact Review for Amendment 11 to the Pacific Coast Groundfish Fishery Management Plan. Pacific Fishery Management Council, 7700 NE Ambassador Place, Suite 200, Portland, OR 97220.

Anon. 2005. Introduction to the Stock Assessment And Fishery Evaluation Report For The Groundfish Resources Of The Gulf Of Alaska. In: North Pacific Fishery Management Council, Gulf of Alaska Groundfish Plan Team (Ed.), NPFMC Gulf of Alaska Stock Assessment And Fishery Evaluation Report. North Pacific Fishery Management Council, The Plan Team for the Groundfish Fisheries of the Gulf of Alaska, Anchorage. 40 pp.

Anon. 2006. Capture Fisheries Statistics of Indonesia, 2004. Directorate General of Capture Fisheries, Ministry of Marine Affairs and Fisheries, Jakarta. 130 pp.

Bachtiar, I. 2000. Community based coral reef management: Lessons learned from the Marine Tourism Park Gili Indah, Lombok Barat. Komunitas (Journal or Rural Studies) 3(1):67-77. 123.

Beverton, F.J.H. & Holt, S.J. 1957. On the dynamics of exploited fish population. Fisheries Investigations from the Ministry of Agriculture Fisheries and Food of Great Britain, Series II, 19. 533 pp.

Brown, D., Staples, D. & Funge-Smith, S. 2005. Mainstreaming fisheries co-management in the Asia-Pacific. Paper prepared for the APFIC Regional Workshop on Mainstreaming Fisheries Co-management in Asia-Pacific, Siem Reap, Cambodia, 9-12 August 2005. RAP Publication 2005/24, FAO, Bangkok. 24 pp.

Burke, L., Selig, E. & Spalding, M. 2002. Reefs at Risk in Southeast Asia. World Resources Institute.

Caddy, J.F. & Mahon, R. 1995. Reference points for fisheries management. *FAO Fisheries Technical Paper*. No. 347. FAO, Rome, 83 pp.

Choat, J.H., Davies, C.R., Ackerman, J.L. & Mapstone, B.D. 2006. Age structure and growth in a large teleost, *Cheilinus undulatus*, with a review of size distribution in labrid fishes. *Marine Ecology Progress Series* 318: 237-246.

Chu, C., Fitzpatrick, C., Kwan, B. & Sadovy, Y. 2006. Final Report: Western Pacific Worshop on Policy, Enforcement and Sustainable Trade for the CITES Appendix II-listed Humphead (Napoleon) Wrasse. 5-7 June, 2006, China, Hong Kong SAR. WWF Hong Kong, AFCD, HK SAR, IUCN and TRAFFIC. 116 pp.

Dorn, M.W. 2002. Advice on West Coast rockfish harvest rates from Bayesian meta-analysis of stock-recruit relationships. *North American Journal of Fisheries Management* 22: 280–300.

FAO. 2000. Fishery Country Profile: Republic of Indonesia. FID/CP/INS Rev.7. May, 2000. http://www.fao.org/fi/fcp/en/IDN/profile.htm.

FAO. 2003. Strategy for Improving Information on Status and Trends of Capture Fisheries. Rome, FAO. 34 pp. (trilingual)

FAO. In prep. Assessment of reef habitat coverage suitable for the Napoleon fish, *Cheilinus undulatus* (CITES Appendix II) in Indonesia using remote sensing. Project Report FIMF/FAO, Rome.

Francis, R.I.C.C. 1992. Use of risk analysis to assess fishery management strategies: a case study using orange roughy (*Hoplostethus atlanticus*) on the Chatham Rise, New Zealand. *Canadian Journal of Fisheries and Aquatic Sciences* 49: 922–930.

Harkes, I. 1999. An Institutional Analysis of Sasi Laut, a Fisheries Management System in Indonesia. paper presented at the ICLARM-IFM International Workshop on Fisheries Co-management, 23-28 August 1999, Penang, Malaysia. 8 pp.

Liermann, M. & Hilborn, R. 1997. Depensation in fish stocks: a hierarchic Bayesian meta-analysis. *Canadian Journal of Fisheries and Aquatic Sciences* 54: 1976-1984.

Little, L.R., Punt, A.E., Mapstone, B.D., Pantus, F., Smith, A.D.M., Davies, C.R. & McDonald, A.D. *In press*. ELFSim – A model for evaluating management options for spatially-structured reef fish populations: An illustration of the 'Larval Subsidy' effect. *Ecological Modelling* 00:00-00.

Mapstone, B.D., Davies, C.R., Little, L.R., Punt, A.E., Smith, A.D.M., Pantus, F., Lou, D.C., Williams, A.J., Jones, A., Russ, G.R. & MacDonald, A.D. 2004. The effects of line fishing on the Great Barrier Reef and evaluations of alternative potential management strategies. CRC Reef Research Centre Technical Report No 52, CRC Reef Research Centre, Townsville, Australia. 205 pp.

Medley, P. 2005. Manual for the monitoring and management of queen conch. *FAO Fisheries Circular* No. 1012. FAO. Rome. 58 pp.

Muller, R.G., Murphy, M.D., Silva, J.D. & Barbieri, L.R. 2003. A stock assessment of yellowtail snapper, *Ocyurus chrysurus*, in the Southeast United States. Florida Fish and Wildlife Conservation Commission, Florida Marine Research Institute, St. Petersbury, Florida. 239 pp.

Munyandorero, J., Murphy, M.D. & MacDonald, T.C. 2006 An assessment of the status of sheepshead in Florida waters through 2004. Florida Fish and Wildlife Conservation Commission, Florida Marine Research, Florida. 113 pp.

Myers, R.A., Bridson, J. & Barrowman, N.J. 1995. Summary of worldwide stock and recruitment data. *Canadian Technical Report of Fisheries and Aquatic Sciences* 2024.

Nikijuluw, V.P.H. Unpublished. Establishment of a local fishery co-management: lessons gained from Bali Island. Report prepared for the Center for Agro Soci-economic Research, (CASER), Agency for Agricultural Research and Development, (AARD), West Java, Indonesia. 15 pp.

Ortiz, M. 2006. Preliminary status of gag grouper in the Gulf of Mexico: continuity run VPA, SEDAR-10. Southeast Fisheries Science Centre, Miami. 30 pp.

Petersen, C.W., Warner, R.R., Shapiro, S.Y. & Marconato, A. 2001. Components of fertilization success in the bluehead wrasse, *Thalassoma bifasciatum*. *Behavioral Ecology* 12: 237-245.

Pet-Soede, C. 2000. Options for co-management of an Indonesian coastal fishery. PhD. Thesis, Wageningen University,Wageningen, The Netherlands, 135 pp.

Pomeroy, R.S. 1995. Community-based and co-management institutions for sustainable coastal fisheries management in Southeast Asia. *Ocean and Coastal Management* 27: 143-162.

Pomeroy, R.S. & Rivera-Guieb, R. 2006. Fishery co-management: a practical handbook. International Development Research Centre, Ottawa, Canada. 223 pp.

Punt, A.E., Garratt, P.A. & Govender, A. 1993. On an approach to applying per-recruit methods to a protogynous hermaphrodite, with an illustration for the slinger *Chrysoblephus puniceus* (Pisces: Sparidae). *South African Journal of Marine Science* 13: 109-119.

Punt, A.E., Smith, D.C. & Koopman, M.T. 2005. Using information for 'data-rich' species to inform assessments of 'data-poor' species through Bayesian stock assessment methods. Final report to Fisheries Research and Development Corporation Project No. 2002/094. Primary Industries Research Victoria, Queenscliff. xiii+243 pp.

Rosser, A.R. & Haywood, M.J. (comps.). 2002. Guidance for CITES Scientific Authorities: Checklist to assist in making non-detriment findings for Appendix II exports. IUCN, Gland, Switzerland and Cambridge, UK. xi + 146 pp.

Sachoemar, S., Suharti, S. & Sadovy, Y. 2006. Preliminary profile on grow-out of the Napoleon fish, *Cheilinus undulatus*, in Indonesia. Unpublished report.

Sadovy, Y. (ed.). 2005. Napoleon Fish (humphead wrasse), *Cheilinus undulatus*, trade in southern China and underwater visual census survey in southern Indonesia. *IUCN Groupers & Wrasses Specialist Group*. 26 pp.

Sadovy, Y. (ed.). 2006. Development of fisheries management tools for trade in humphead wrasse, *Cheilinus undulatus*, in compliance with Article IV of CITES. *IUCN Groupers & Wrasses Specialist Group*. Final Report April 2006, 103 pp.

Sadovy, Y., Kulbicki, M., Labrosse, P., Letourneur, Y., Lokani, P. & Donaldson, T.J. 2003. The humphead wrasse, *Cheilinus undulatus*: synopsis of a threatened and poorly known coral reef fish. *Reviews in Fish Biology and Fisheries* 13: 327-364.

SEDAR. 2004. Stock Assessment of the Deepwater Snapper-Grouper Complex in the South Atlantic, Charleston, South Carolina. 382 pp.

SEDAR. 2006a. SEDAR 10 Stock Assessment Report: South Atlantic Gag Grouper SEDAR 10 Stock Assessment Report. SEDAR, Charleston, South Carolina. 449 pp.

SEDAR. 2006b. Stock Assessment Report of SEDAR 9: Gulf of Mexico Gray Triggerfish. SEDAR, Charleston, South Carolina. 195 pp.

SEDAR. 2006c. Stock Assessment Report of SEDAR 9: Gulf of Mexico Vermilion Snapper. SEDAR, Charleston, South Carolina. 231 pp.

SEDAR. 2006d. Complete Assessment of Review Report of South Atlantic Vermillion Snapper. SEDAR, Charleston, South Carolina. 112 pp.

SEDAR. 2006e. Stock Assessment of Red Porgy off the Southeastern United States : SEDAR Update Assessment. SEDAR, Beaufort, North Carolina. 152 pp.

SEDAR. 2006f. Report of Stock Assessment: Black Sea Bass SEDAR Update Process #1. SEDAR, Beaufort, North Carolina. 172 pp.

SEDAR 2006g. Stock Assessment Report of SEDAR 9: Gulf of Mexico Greater Amberjack, SEDAR, Charleston, South Carolina. 178 pp.

Sissenwine, M.P. & Shepherd, J.G. 1987. An alternative perspective on recruitment overfishing and biological reference points *Canadian Journal of Fisheries and Aquatic Sciences* 44: 913–918.

Spalding, M.D., Ravilious, C. & Green, E.P. 2001. *World Atlas of Coral Reefs*. University of California Press, Berkeley. 424 pp.

Vasconcellos, M. & Cochrane, K. 2005. Overview of world status of data-limited fisheries: inferences from landing statistics. pp. 1-20. In: G.H. Kruse, V.F. Galluci, D.E. Hay, R.I. Perry, R.M. Peterman, T.C. Shirley, P.D. Spencer, B. Wilson and D. Woodby (eds.). Fisheries assessment and management in data-limited situations. Alaska Sea Grant College Program, University of Alaska Fairbanks.

APPENDIX A: Meta-analysis of steepness of the stock-recruitment relationship for coral reef fishes

The approach applied by Dorn (2002) and by Punt, Smith and Koopman (2005) to construct a Bayesian posterior distribution for the steepness, *h*, of the stock-recruitment relationship for an unknown stock is used as the basis for deriving the probability distribution for the steepness parameter for Napoleon fish.

A.1 Priors and likelihoods

A.1.1 The model of the data

Stock and recruitment data are available for a wide range of marine taxa (e.g. Myers, Bridson and Barrowman, 1995). However, most of the data sets are for short-lived and highly productive temperate fishes. Moreover, although data are limited, it appears that species that are not clupeiformes, pleuronectiformes, and gadiformes are, in general, less productive. Therefore, it was decided to base the probability distribution for steepness for Napoleon fish on data for reef-associated species only. The available data are estimates of spawning biomass and recruitment for 12 stocks of tropical coral reef-associated fishes (see Table A.1). Time-series of stock and recruitment data from tropical reef fish stocks are not available for the majority of exploited stocks except in the United States, which limits the size of database on which analyses can be based. Based on the life history parameters used in the original stock assessments, spawning biomass-per-recruit in the absence of fishing mortality ($SSB/R_{F=0}$) was calculated for each stock using the equation:

$$SSB/R_{F=0} = \sum_{a=0}^{T} l_a m_a x_a \qquad \text{(A.1)}$$

where l_a is the survivorship to age *a*,
m_a is the proportion of mature fish at age *a*, and
x_a is weight or fecundity per individual at age *a*.

Units of $SSB/R_{F=0}$ conform to the stock-recruitment data from the original assessment (see Table A.2).

The relationship between the estimates of spawning biomass and recruitment is assumed to be the Beverton-Holt form of the stock-recruitment relationship, and the error structure is assumed to be log-normal. For a single stock, the contribution of the data to the likelihood function is given by:

$$L(D \mid h, R_0, \sigma_R) = \prod_i \frac{1}{\sqrt{2\pi}\sigma_R R_i} \exp\left[-\frac{\left(\ell n R_i - \ell n \hat{R}(S_i) + \sigma_R^2/2\right)^2}{2\sigma_R^2}\right] \qquad \text{(A.2)}$$

where R_i is the i[th] recruitment,
S_i is the i[th] spawning biomass, and
$\hat{R}(S)$ is the model-predicted recruitment corresponding to a spawning biomass of *S* (note that $\hat{R}(S)$ depends on *h* and R_0).

Note that, as in Dorn (2002), the likelihood formulation is based on the recruitment from the stock-recruitment relationship being the mean of the distribution rather than the more conventional assumption that it is the median of the distribution.

The likelihood of the total (across all stocks) data set is given by:

$$L(D \mid \underline{h}, \underline{R}_0, \underline{\sigma}_R) = \prod_k \prod_i \frac{1}{\sqrt{2\pi}\sigma_{R,k} R_{i,k}} \exp\left[-\frac{(\ell n R_{i,k} - \ell n \hat{R}_k(S_{i,k}) + \sigma_{R,k}^2/2)^2}{2\sigma_{R,k}^2} \right] \quad \text{(A.3)}$$

where $R_{i,k}$ is the i[th] recruitment for stock k,

$S_{i,k}$ is the i[th] spawning biomass for stock k,

$\hat{R}_k(S)$ is, for stock k, the model-predicted recruitment corresponding to a spawning biomass of S,

h_k is the steepness of the stock-recruitment relationship for stock k (i.e. for stock k, the fraction of the virgin number of age-0 animals to be expected when the mature female biomass is reduced to 20 percent of the virgin mature female biomass),

$R_{0,k}$ is the virgin recruitment for stock k, and

$\sigma_{R,k}$ is the standard deviation of the fluctuations about the stock recruitment relationship for stock k.

A.1.2 The prior and hyperprior distributions

The prior for steepness is defined in terms of the logit of steepness. This prior is normal with mean μ and variance τ, i.e.:

$$P(\underline{h} \mid \mu, \tau) = \prod_k \frac{1}{\sqrt{2\pi\tau}} \exp\left[-\frac{(\tilde{h}_k - \mu)^2}{2\tau} \right] \quad \text{(A.4)}$$

where $\tilde{h}_k$ is the logit-transformed steepness, i.e.:

$$\tilde{h}_k = \ell n \left(\frac{h_k - 0.2}{1 - h_k} \right) \quad \text{(A.5)}$$

The logit of steepness is assumed to be normally distributed because Eqn A.5 takes a variable that is defined between 0.2 and 1 (steepness) and transforms it to a variable between -∞ and ∞. The remaining two parameters of the model are virgin recruitment and the standard deviation of the random fluctuations about the stock-recruitment relationship, σ_R. The prior distribution for the logarithm of σ_R is assumed to be uniform over the interval $U[-\infty, \infty]$ while a relatively uninformative prior is placed on virgin recruitment. This prior, following Dorn (2002), is a normal distribution with mean for stock k given by the average of the observed recruitments for stock k when the observed spawning biomass exceeds the median observed spawning biomass for stock k, and a coefficient of variance of 3, i.e.:

$$P(\underline{R}_0) = \prod_k \frac{1}{\sqrt{2\pi}\, 3\bar{R}_{0,k}} \exp\left[-\frac{(R_{0,k} - \bar{R}_{0,k})^2}{2(3\bar{R}_{0,k})^2} \right] \quad \text{(A.6)}$$

where $\bar{R}_{0,k}$ is the observed average recruitment when the observed spawning biomass exceeds the median observed spawning biomass.

It is necessary to place a hyperprior on the parameters of the prior for the logit of steepness to finalize the specification of the prior. Following Dorn (2002) again, the hyperprior is chosen to be relatively uninformative so that the posteriors for h are driven primarily by the data rather than by the choice of the prior distribution. In particular, the prior for μ is assumed to be uniform over a wide interval [-1000, 1000] while the prior for τ is taken to be a scaled inverse chi-squared distribution, i.e.:

$$P(\tau)=\frac{\left(\frac{v}{2}\right)^{(v/2)} s^{v}\exp\left(-\frac{vs^{2}}{2\tau}\right)}{\Gamma\left(\frac{v}{2}\right)\tau^{(v/2+1)}} \tag{A.6}$$

where v (=10) and s^2 (=0.5) are the parameters of the hyperprior.

A.2 Computational aspects

It is impossible to evaluate the posterior distribution analytically so it is necessary to rely on numerical methods to represent this distribution. For the purposes of this report, samples are drawn from the posterior distribution using the Markov Chain Monte Carlo algorithm as implemented in the AD Model Builder package[5]. A total of 20 000 000 cycles were carried out of which the first 10 percent were discarded as a burn-in and the chain was thinned further by sub-sampling every 5 000th element. Whether convergence had been achieved was determined by applying standard diagnostic statistics and plots (e.g. Punt, Smith and Koopman, 2005).

A.3 Determining the posterior for steepness for an unknown stock

The posterior distribution for steepness for Napoleon fish is set equal to that for an "unknown stock" because Napoleon fish is not one of the stocks for which data on recruitment and spawning biomass are available (see Table A.1). The steps involved in constructing a posterior distribution for the steepness of an unknown stock are:

1) Sample values for μ and τ from the joint posterior distribution.
2) Sample a value for $\tilde{h}$ from $N(\mu,\tau)$.
3) Calculate $h=[0.2+\exp(\tilde{h})]/[1+\exp(\tilde{h})]$.
4) Repeat steps 1) – 3) many times.

[5] © Otter Software.

Table A.1. The data sets used in the meta-analysis.

Stock	Years	References
Gag grouper (Gulf of Mexico)	1984-2004	Oritz (2006)
Gag grouper (South Atlantic)	1962-2005	SEDAR (2006a)
Gray triggerfish	1986-2004	SEDAR (2006b)
Vermillion snapper (Gulf of Mexico)	1981-2004	SEDAR (2006c)
Vermillion snapper (South Atlantic)	1976-2000	SEDAR (2006d), Erik Williams (pers. comm.)
Red porgy	1972-2005	SEDAR (2006e)
Sheephead (Gulf coast)	1982-2004	Munyandorero, Murphy and MacDonald (2006)
Sheephead (South Atlantic)	1982-2004	Munyandorero , Murphy and MacDonald (2006)
Snowy grouper	1974-2002	SEDAR (2004)
Yellowtail snapper	1981-2001	Muller *et al.* (2003)
Black sea bass	1978-2004	SEDAR (2006f)
Greater amberjack	1987-2004	SEDAR (2006g)

Table A.2. The estimated spawning biomass per recruit in the absence of fishing mortality ($SSB/R_{F=0}$)for each stock.

Stock	$SSB/R_{F=0}$	Unit (per recruit)	Recruit age
Gag grouper (Gulf of Mexico)	0.0485	Million t of gutted female	0
Gag grouper (South Atlantic)	53.657	Lbs of fish	0
Gray triggerfish	3.500	Million eggs	0
Vermillion snapper (Gulf of Mexico)	15.003	Million eggs	1
Vermillion snapper (South Atlantic)	2.005	Million eggs	0
Red Porgy	2.692	Tonnes (t) of fish	0
Sheephead (Gulf coast)	3.364	Thousand t of female	0
Sheephead (South Atlantic)	2.876	Thousand t of female	0
Snowy grouper	0.028	Million t of fish	0
Yellowtail snapper	1.987	Thousand t of female	0
Black sea bass	1.185	Thousand t of fish	0
Greater amberjack	0.067	t of fish	0

t = tonnes

APPENDIX B: Default values for the amount of illegal, unreported and unregulated (IUU) fishing exports and domestic consumption of Napoleon fish

A default value for the amount of IUU exports can be calculated (roughly) using 2005 data in Table 4 of Sadovy (2006) which provides AFCD and CSD (governmental statistics departments of Indonesia) information on imports of Napoleon fish from Indonesia. Estimates can be updated as more recent data become available.

The imports by air (CSD) were 4 619 kg while the estimated imports by sea (AFCD) were 14 059 kg, of which most was from Indonesia as indicated by AFCD. Assuming that 50 percent of the imports by sea were from Indonesia (a conservative assumption), this means that imports to China, Hong Kong SAR, for 2005 were at least 11 649 kg (roughly 11 649 fish assuming, conservatively, that 1 fish = 1 kg (based on preferred market sizes and hence the sizes that tend to be selected for trade). The IUU removal was 3 649 animals, if the quota was 8 000 animals (as the export quota was for Indonesia for 2006), or 46 percent. This value is likely to underestimate the true extent of IUU fishing/mortality in transit because it does not account for the mortality of fish in transit from exporting to importing ports.

The domestic catch of Napoleon fish reported by the Government of Indonesia to FAO for 2004 and 2005 was 115 t and 100 t respectively (Anon., 2006).

APPENDIX C: Performance of status and characteristics of Napoleon fish in grow-out phase within the Indonesian waters (reproduced with permission from Sachoemar, Suharti and Sadovy [2006]). Method codes are: a (phone), b (local partner) and c (visit).

No.	Collector	Address	Purchased / Received			Grow out				Fish	Remarks	Methods
			Direct export (%)	Grow-out (%)	Sell to local market (%)	First input size	Duration (month)	Mortality (%)	Sell size	Originated		
1	CV. Global Master	Sorong, Papua	-	100	-	300 g	7-24	30	1-3 kg	Raja Ampat Sorong, Papua	Mortality due to feed problem	a, b
2	Fredi Marjuddin	JL.Pahlawan 190 Kupang East Nusa Tenggara	-	-	100	-	-	-	-	Timor Sea	First catch size 1-3 kg Quarantine in cage 14 d Mortality 30 %	a, b, c
3	Mat Mahmud Location of GO	Likupang, Minahasa North Sulawesi Nain Island	-	90	10	20-30 cm	6-12	25	> 50 cm	Likupang, Nain Island-Bunaken North Sulawesi		a, b, c
4	CV. Rudiana	JL.Gunung Latimojong 74/21, Makasar South Sulawesi Fax :320762	-	-	100	-	-	-	-	Pangkep, Sinjai Selayar, South Sulawesi	First Catch size 300-400 gr	a, b, c
5	CV.Winka Location of GO	JL.Sulawesi 52 Makasar South Sulawesi Balang Cakdii Island	70	30	-	300-400 g	24	25-30	1 kg	South, north, southeast Sulawesi, Maluku Papua		a, b, c
6	CV.Udin Jaya Location of GO	JL.Sabutung I No.1 Makasar South Sulawesi Ph.3027194 JL.Pasar Ikan (Kayu Bangkoa)	-	30	70	300 g	12-18	30	1 kg	Takalar Pangkep, Sinjai Selayar, South Sulawesi		c

No.	Collector	Address	Purchased / Received			Grow out				Fish	Remarks	Methods
			Direct export (%)	Grow-out (%)	Sell to local market (%)	First input size	Duration (month)	Mortality (%)	Sell size	Originated		
7	Mukti	Pagametan, Singaraja Bali	-	100	-	7-8 cm/ 100 g	12	50-80	0,5 kg	Madura (East Java)	Sold to collector at Denpasar	a, b ,c
	Location of GO	Pagametan										
8	Setiawan	Tanjung Putu Lampung Hp. 08118141929	-	100	-	300-400 g (12-15 cm)	>24	30	Not Sold	Lampung	GO for private collect (brood stock: 5-7 kg/f)	a, b ,c
	Location of GO	Tanjung Putus										
9	PT.Kedamaian Makmur Sejahtera	JL.Ir.Sutemi KM 9 Way Laga, Lampung Ph. 33897	-	100	-	500 g (25 cm)	24	5	>500 g	Lampung		a, b ,c
	Location of GO	Tarahan-Pulau Condong										
10	Killy Jaya	Perumahan Sumber Jaya 14, Teluk Betung Ph. 7402928 Lampung	20	80	-	350-400 g (18 cm)	12-18	10	>500 g	West Sumatera Riau, Lampung		c
	Location of GO	Siuncal Island										
11	Landu	Legundi Island Lampung	-	-	100	-	-	-	-	Lampung	Catch size 300-400g	a, b ,c
12	Bedu	Tanjung Putus Lampung	-	-	100	-	-	-	-	Lampung	Catch size 300-400g	a, b
13	Lucas	Tanjung Putus Lampung	-	100	-	250-300 g (12-15 cm)	12	0	>500 g	Lampung		a, b

No.	Collector	Address	Purchased / Received			Grow out				Fish	Remarks	Methods
			Direct export (%)	Grow-out (%)	Sell to local market (%)	First input size	Duration (month)	Mortality (%)	Sell size	Originated		
14	Rika Sudranto (Sea World)	Lampung Hp. 811968508	-	100	-	300-500 g	>24	0	Not Slod		For their own display	a, b
15	Kelompok Nelayan Lestari Location of GO	Desa Sungai Padang Belitung Belitung Island	-	100	-	>200 g	12	0	>500 g (>30 cm)	Karimata Island Belitung		a, b, c
16	PT.Trimina Dinasti Agung Location of GO	JL.MT.Haryono No.8 Tanjung Pinang,Riau Bintan Island	-	100	-	300-400 g	12-24	10	>500 g	West, South, East Sumatera		
17	Rizaldi	Kecamatan Sedanau Natuna	-	100	-	4-9 cm	12-24	5-7	1.5-2 kg	Natuna	Export to China, Hong Kong SAR	a, b
18	W.Murrad	Kecamatan Pulau Tiga Natuna				9 cm	24	3-5	30-55 cm	Natuna	Export to China, Hong Kong SAR	a, b, c
19	Daeng Jamaludin	Kecamatan Pulau Tiga Natuna	-	100	-	4-9 cm	24	5-7	30-40 cm	Natuna	Export to China, Hong Kong SAR	a, b, c
20	Bakar	Kecamatan Pulau Tiga Natuna	-	100	-	4-6 cm	24	3-5	30-55 cm	Natuna	Export to China, Hong Kong SAR	a, b, c
21	Umran	Kecamatan Pulau Tiga Natuna	-	100	-	5-10 cm	24	5-7	35-45 cm	Natuna	Export to China, Hong Kong SAR	a, b, c
22	Kamaruddin	Kecamatan Pulau Tiga Natuna	-	100	-	4-7 cm	24	5-7	35-40 cm	Natuna	Export to China, Hong Kong SAR	a, b, c
23	Noto	Kecamatan Pulau Tiga Natuna	-	100	-	4-9 cm	48	5-7	40-65 cm	Natuna	Export to China, Hong Kong SAR	a, b, c

APPENDIX D. A user-interface for a stock assessment model of the humphead (=Napoleon) wrasse

D.1. Introduction

A user-interface was developed to facilitate the use of the model outlined in the main text. This user-interface aims to allow a user with basic fisheries training to apply the model, understand the sensitivity of the estimated quotas to the inputs, and identify possible areas needing further research or data collection. In the following sections the main features of the user interface are described and some recommendations for users are provided. The Annex to this Appendix includes a complete description of labels and associated help remarks in the user-interface.

D.2. Description of the user-interface

Simulation of population dynamics

The user-interface was developed using Visual Basic for Applications in Microsoft Excel[6] and builds on the population dynamics model described above. The structure of the user-interface is described schematically by a flowchart (Figure D.1).

The user-interface activates automatically when the Excel file is opened. In some cases, users should lower the Macro Security level in Excel (go to Tools > Options > Security > Macro Security) to no more than "Medium". An introduction page is shown as the file is opened. The introduction page provides a brief introduction of the objective and the structure of the model through the front page and the HELP forms (Figure D.2).

---

[6] The MS Excel file (Napoleon.xls) with the user-interface is provided in the CD-ROM attached to this report. The file can also be obtained directly from the authors.

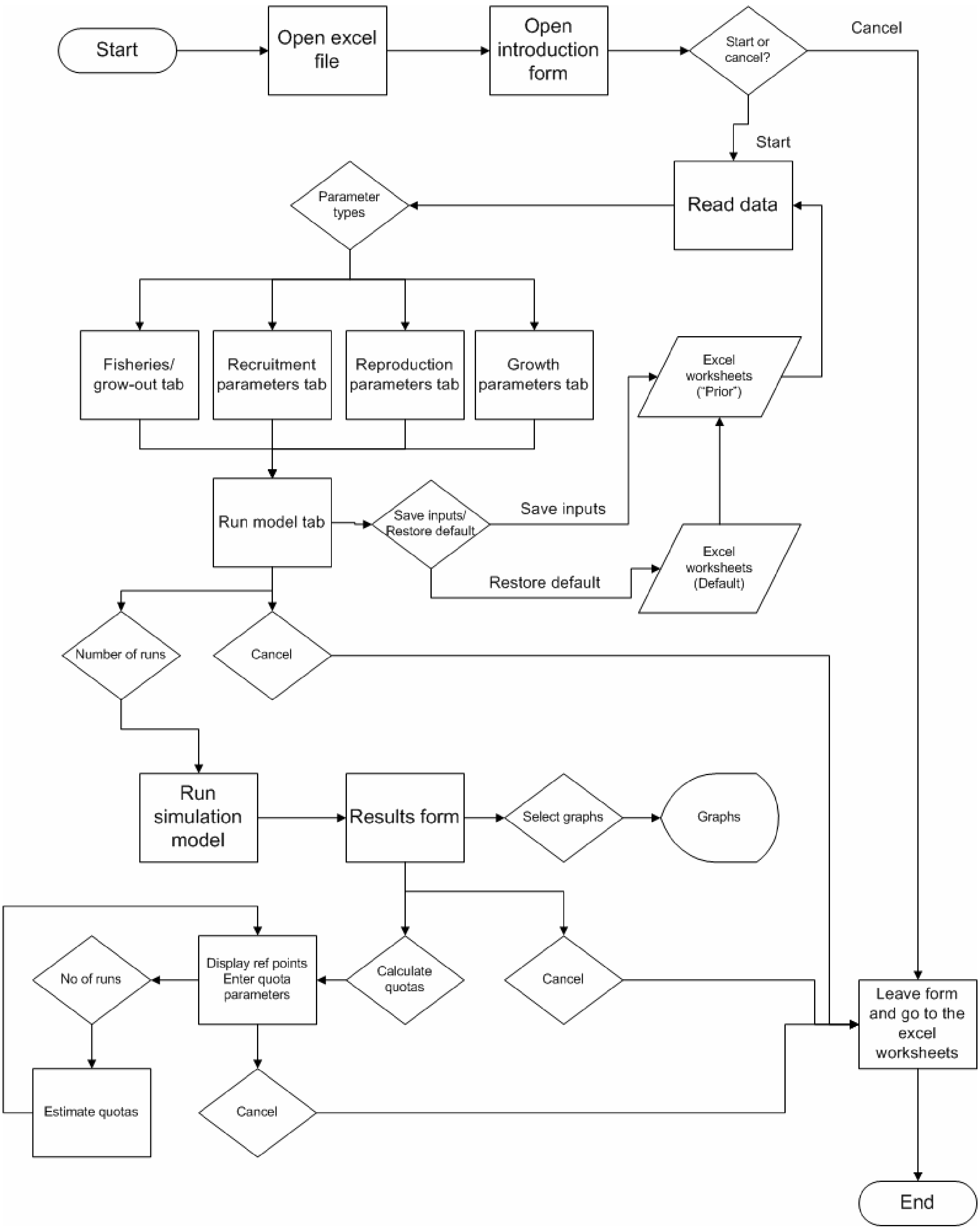


Figure D.1. Diagram outlining the structure of the user-interface for the Napoleon fish model.

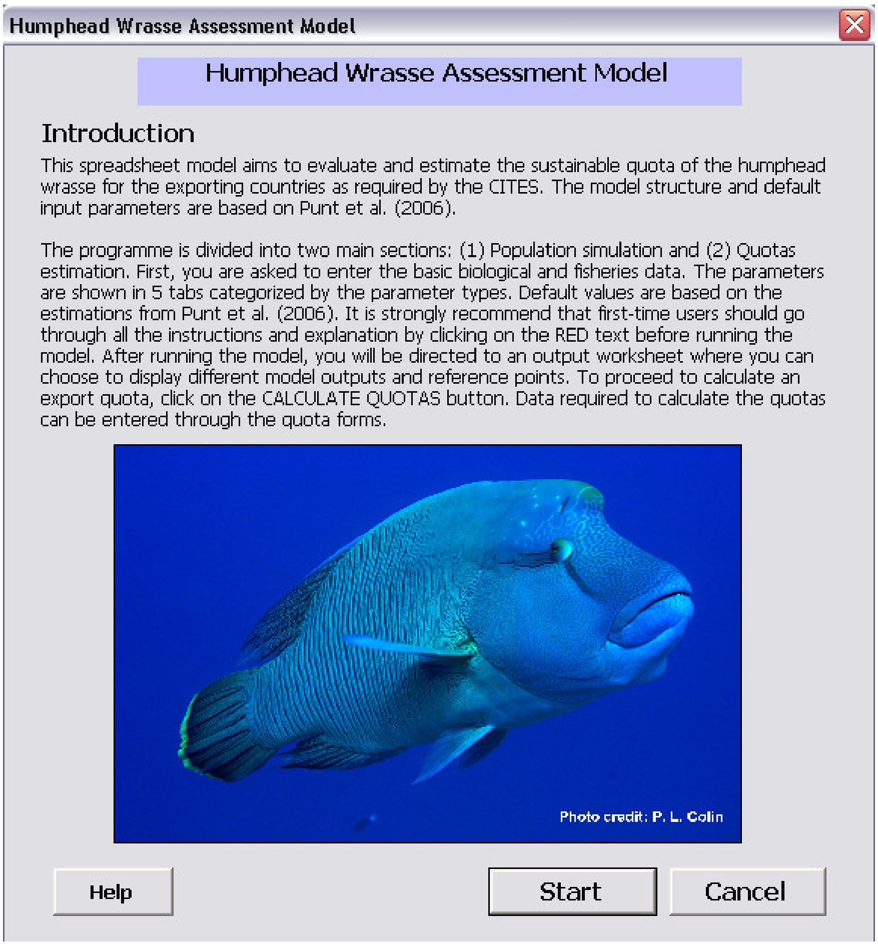


Figure D.2. Introduction page for the Napoleon fish model interface.

Users enter the first input form (Figure D.3) by pressing the "Start" button. The input forms are structured in tab-page format. The five tab-pages are defined by the parameter types: Growth, Reproduction, Recruitment, Fisheries/grow-out and the parameters needed to Run the model. Default values for the parameters have been assigned based on the analyses in this report. However, users are strongly advised to go through ALL tabs and parameters before running the model.

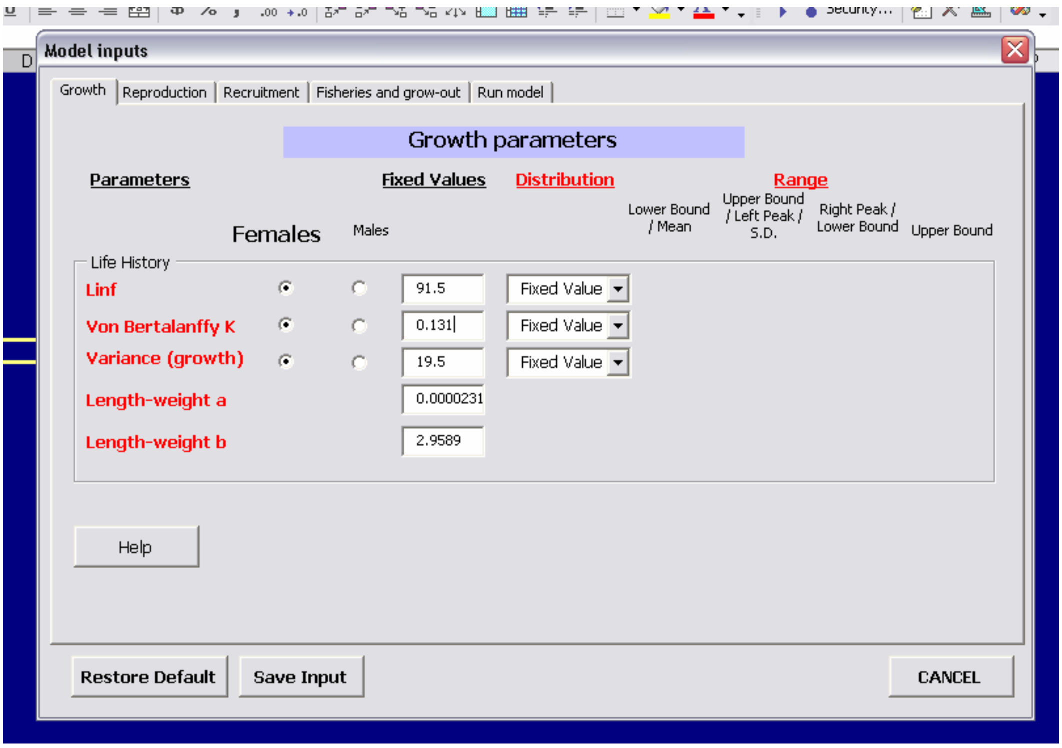


Figure D.3. Input form for the Napoleon fish model interface.

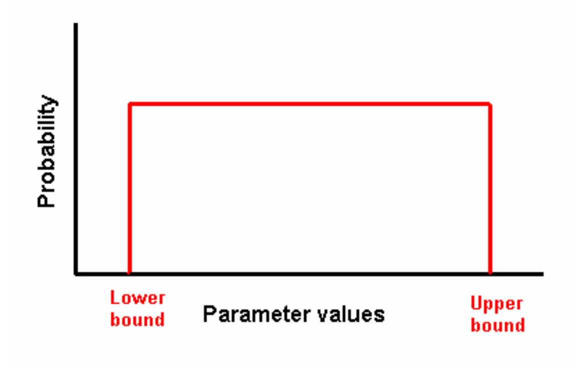
Help and instructions can be found in every tab. Explanations and definitions of selected parameters can be viewed by clicking on the parameter labels highlighted in Red. For instance, if users click on the L_{inf} label on the growth tab, a message box with explanation of what L_{inf} is and how the default value was estimated will appear. Moreover, explanations on the tab concerned (e.g. Growth) can be obtained by clicking on the "Help" button.

Rather than providing a single value, based on the "best estimate" of the parameter, users can choose to assign a probability distribution to many of the parameters. Although the default is often a fixed value, users also have the option to specify a uniform, trapezoid or normal distribution by choosing the particular form under the combo-box "Distribution". For a uniform distribution, the model requires the upper and lower bounds for the value of the parameter. For the trapezoid distribution, the model requires left and right peaks, in addition to upper and lower bounds. For the normal distribution, the mean, standard deviation, and upper and lower bounds are required (Figure D.4). Based on the different availability of data for each sex, different distributions can be specified for males and females. It is advisable to assign a distribution for a parameter whose value is uncertain so that the impact of that uncertainty on the model outputs can be evaluated.

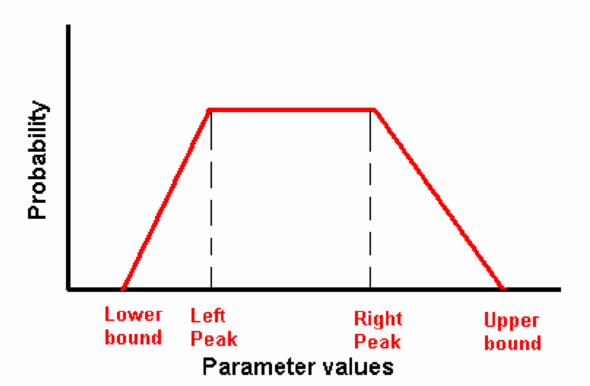
Growth tab

Users can specify the values for the basic growth parameters: asymptotic length (L_{inf}), von Bertalanffy growth parameter (K), the variance of the annual growth increment (σ^2), and the coefficients for the length-weight relationship. The first three of these parameters are sex-specific because Napoleon fish, like many reef fishes, is protogynous.

a)



b)



c)

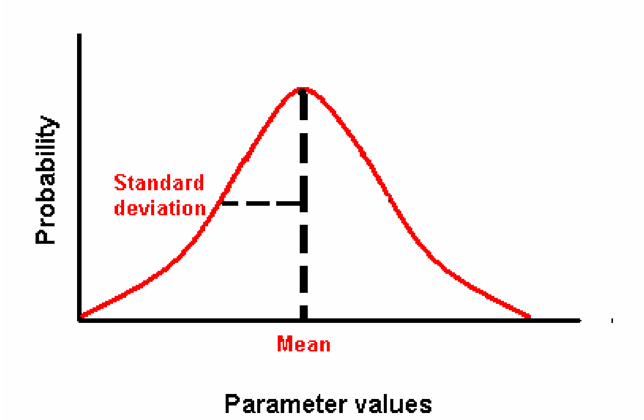


Figure D.4. Prior distributions that can be specified in the input form: (a) uniform, (b) trapezoid and (c) normal.

Reproduction tab

In this page, users can specify the parameters related to the reproduction component of the model (Figure D.5). These parameters are the coefficients of the female gonad weight-length relationship, the instantaneous rate of natural mortality for wild animals, the rate of sex change from female to male, the lowest length at maturity, the lengths at 50 percent and 95 percent maturity, the smallest size at sex change and the largest size at sex change. Users can specify a uniform, trapezoid or normal distribution for the parameters (except the smallest and highest size at sex change) instead of using fixed values.

Users can also plot the maturity ogive and the length-gonad weight relationship by pressing the "Plot maturity" and "Plot weight" buttons. This allows the user to visualize the maturity ogive and length-gonad weight relationship that they specified and hence the effects of changing the values for these parameters from their defaults (Figure D.6). However, the parameters must be specified as "fixed values’ to plot the curves. If parameters are specified as "distribution" instead, an error message will appear asking the user to revise the input parameters. Users can go back to the input form from the plots by pressing the button "Go to input form" (Figure A.6).

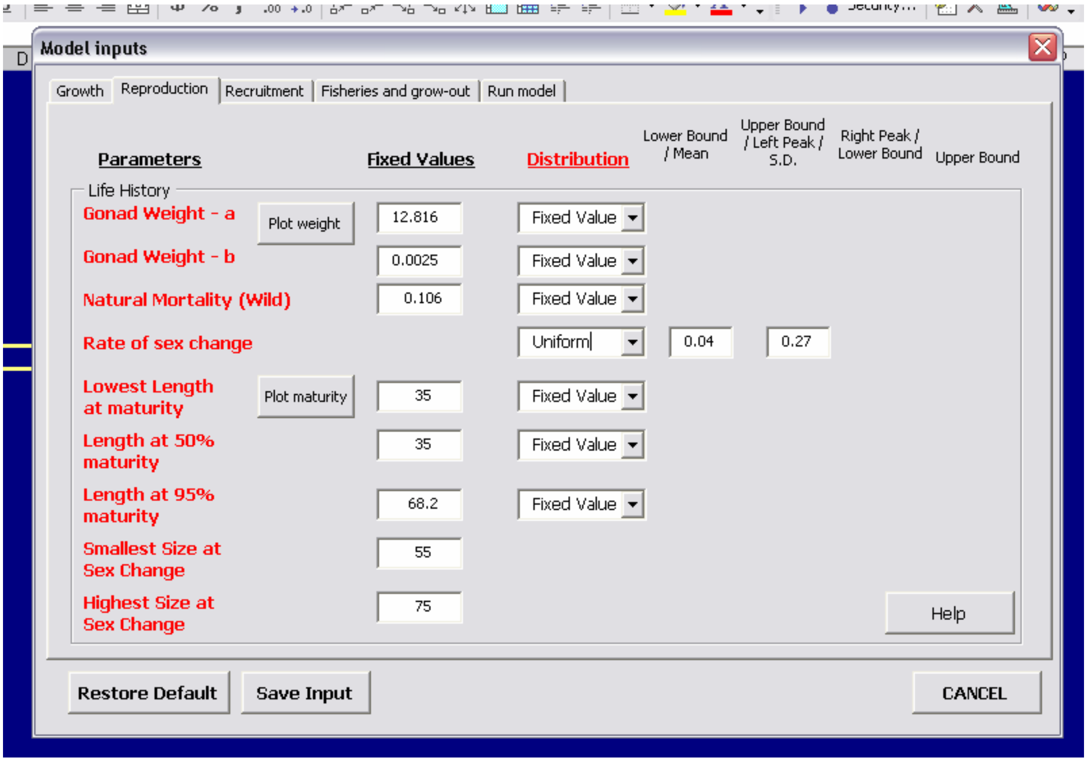
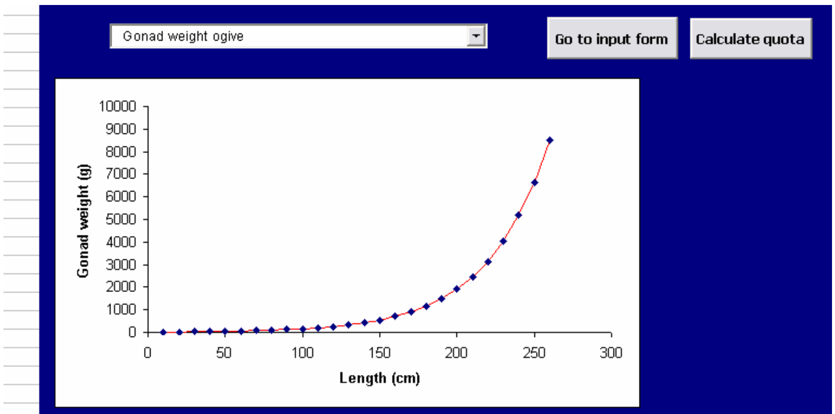


Figure D.5. Reproduction input parameter tab.

a)



b)

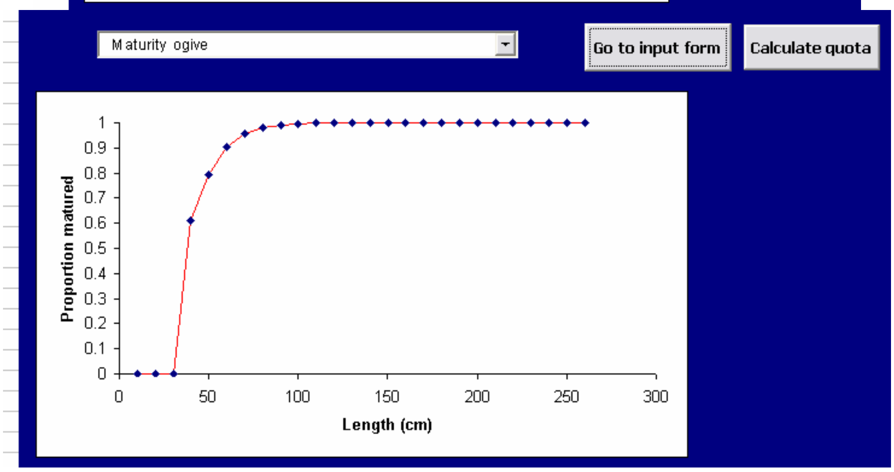


Figure D.6. Examples of the gonad weight-body length relationship and the maturity ogive.

Recruitment tab
Users can specify the parameters related to recruitment in this page (Figure D.7). The parameters include the steepness of the stock-recruitment relationship (the fraction of the virgin number of age-0 animals expected when the total female gonad weight is reduced to 20 percent of the virgin total female gonad weight). In addition to the uniform, trapezoid and normal distributions, users can choose to use a logit-transformed normal distribution for the steepness parameter (see Appendix A for details). The stock-recruitment relationship is assumed to be of the Beverton and Holt form, and this cannot be changed.

The users can choose to change the values for the parameters governing the impacts of sex ratio on recruitment by clicking on the check box "Check to specify the possible impact of sex-ratios imbalance on recruitment". The parameters that determine the impact of sex ratio on recruitment include the female to male sex ratio above which the fertilization rate might reasonably be expected to decline (default critical female: male sex-ratio = 50:1) and the parameter that determines how rapidly fertilization rates decline with increasing sex-ratio (Sex ratio impact rate). The impacts of sex-ratio imbalance on recruitment of Napoleon fish are unclear. Therefore, this option is not chosen in the base-line analyses, and the default value for the impact rate is 0 (i.e. no impact). However, users may activate and increase the critical impact rate to evaluate the effects on the population and model outputs such as export quotas.

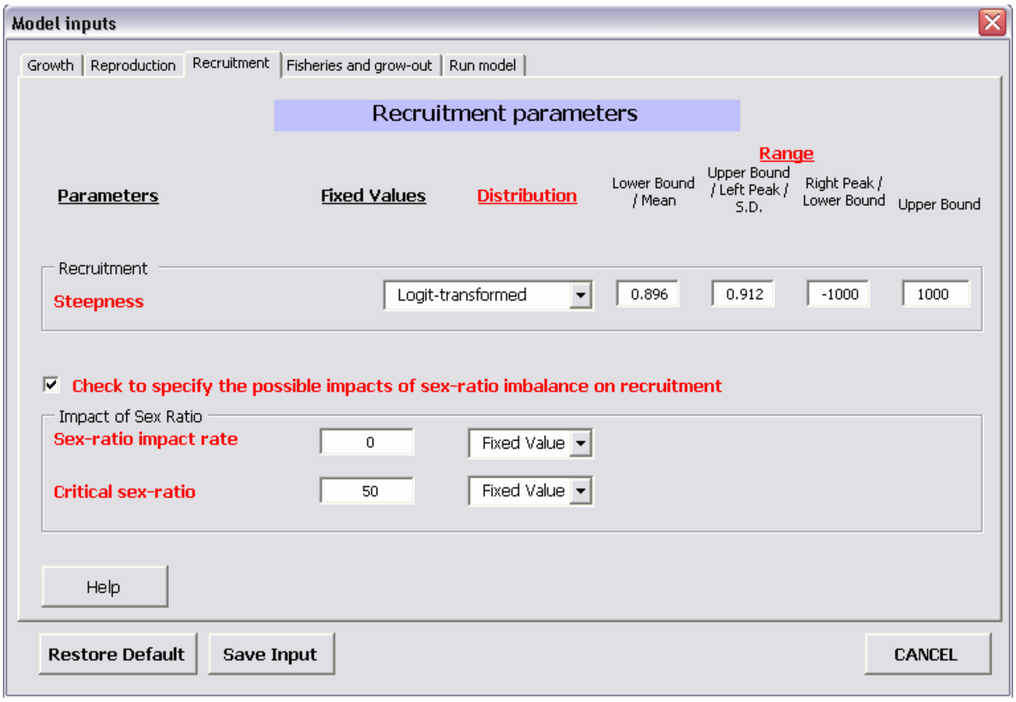


Figure D.7. Recruitment parameters input tab.

Fisheries and grow-out tab
Users can change the values for the three parameters of the selectivity ogive: the length-at-modal selectivity, the variance of the selectivity function and the constant term (Figure D.8). Gear selectivity by size is assumed to have a log-normal shape with a constant value added (see Section 2.3.6 of this report for how the values for the parameters of this selectivity function were estimated). The selectivity ogive is rescaled so that maximum selectivity is one. The user can plot the selectivity ogive by pressing the "Plot ogive" button (Figure D.9). This allows visualization of the effects of changing the selectivity parameters from the defaults. However, parameters must be "fixed values" to plot the ogive or an error message will appear.

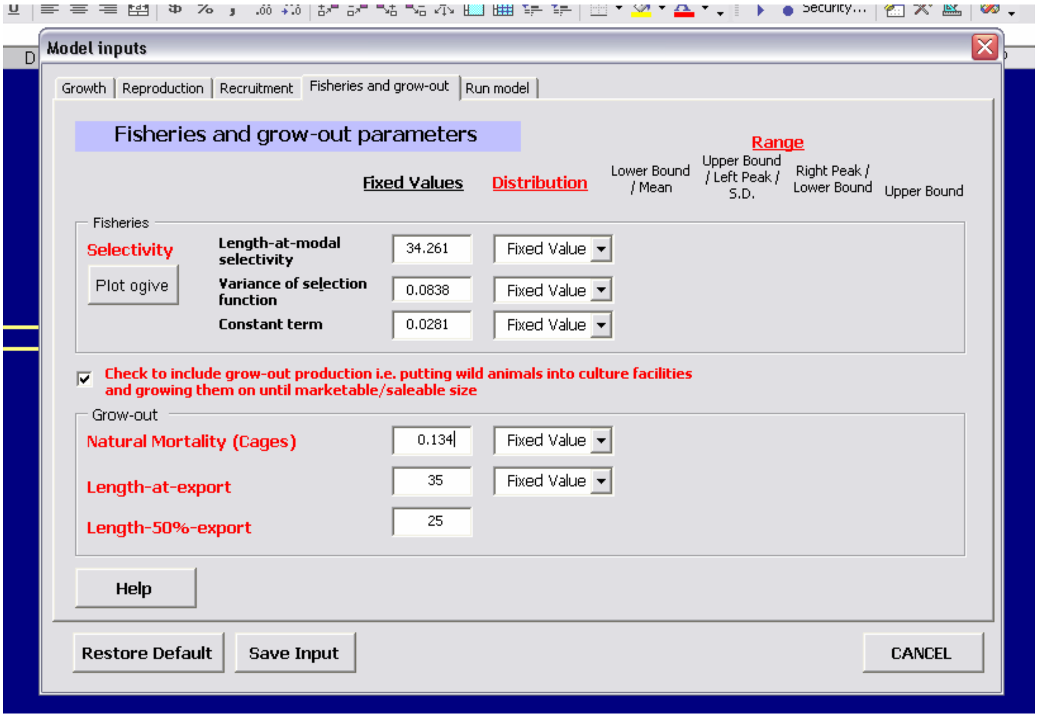


Figure D.8. Fisheries and grow-out tab.

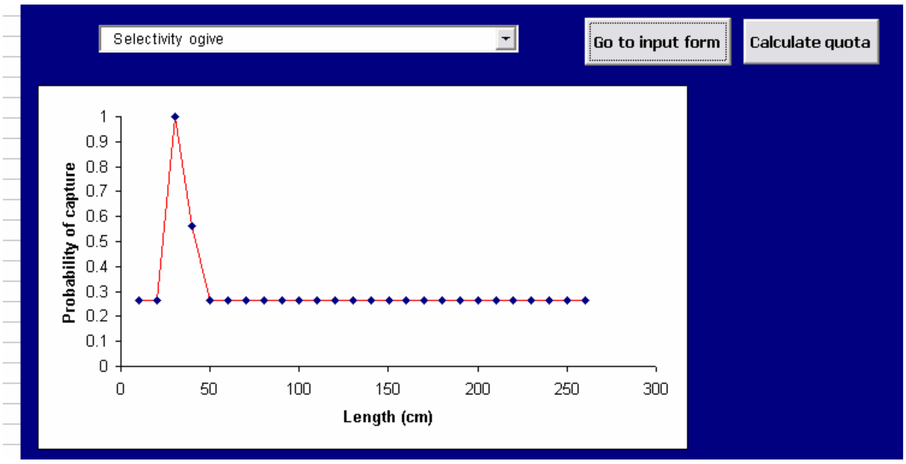


Figure D.9. The selectivity ogive.

Production from grow-out is included in the model by default and users should choose to de-activate the "grow-out" option if grow-out does not occur and contribute to exports. It is important to carefully consider the inclusion/exclusion of grow-out as this may have considerable impacts on the wild population and on the estimation of export quotas. Users can specify the natural mortality rate of the animals in grow-out facilities, the minimum size at which the animals in grow-out facilities are exported, and the size at which 50 percent of the captured animals are directly exported without being kept in cages.

Run model tab

Finally, before running the model, users are asked to specify the number of Monte Carlo simulation runs, the range of fishing mortality rates to be examined, and the step size for fishing mortality (Figure A.10). The number of Monte Carlo runs depends on the levels of uncertainty that are specified by the user for each parameter. The more uncertain the parameters (for instance, uniform distribution with a wide range), the greater the number of Monte Carlo runs that are required to allow the outputs to be estimated with reasonable precision. On the other hand, every Monte Carlo run would lead to the same results if no uncertainty is specified (i.e. if fixed values are used for every parameter). Generally, users should specify 200-1000 runs (200 is set as default). It is recommended that the results are examined for various numbers of Monte Carlo runs to determine whether the number of runs is enough. After running the model, users can go to the worksheet "MonteResults" and copy the outputs to another spreadsheet.

Error messages will appear if the input parameters in the five tabs are incorrectly specified. For instance, an error message will appear after the run button is pressed asking the user to revise the input parameters if a uniform distribution for asymptotic length (female) is selected, but the value for the lower bound is higher than that of the upper bound.

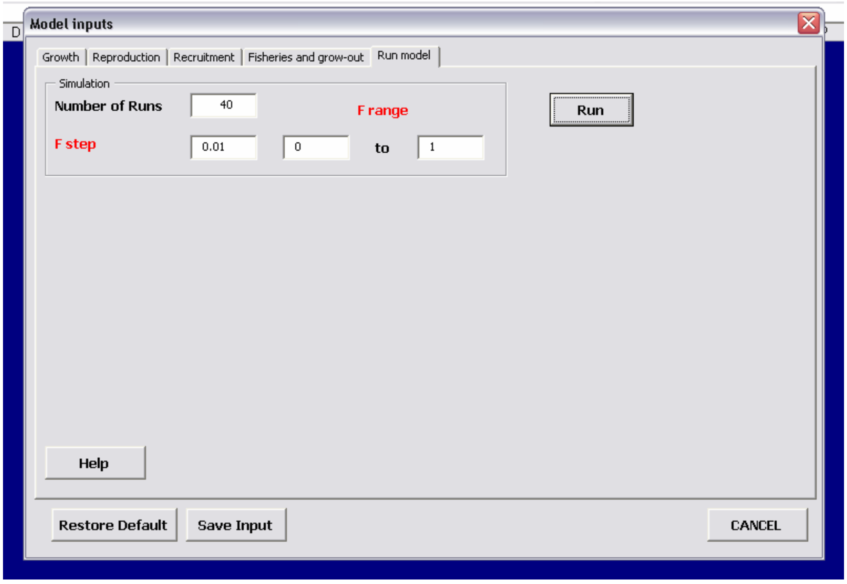


Figure D.10. Run model tab.

If the input parameters are correctly specified, Monte Carlo simulations will be conducted based on these specifications. The progress of the calculation is indicated on the form (Figure D.11). The amount of time required to complete the simulation depends on the computer used, the number of simulation runs, the fishing mortality step size, and the range of fishing mortality rates. To shorten the simulation time, users can increase the step or reduce the range of fishing mortality rates. However, this will lead to a lower resolution for the output.

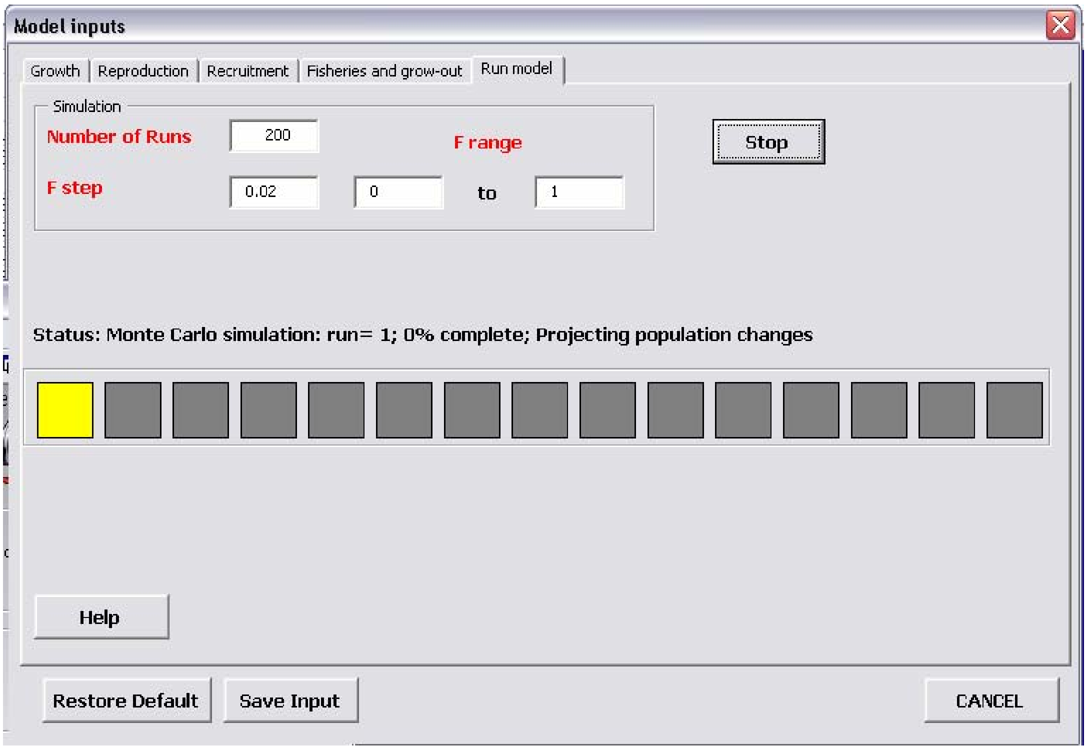
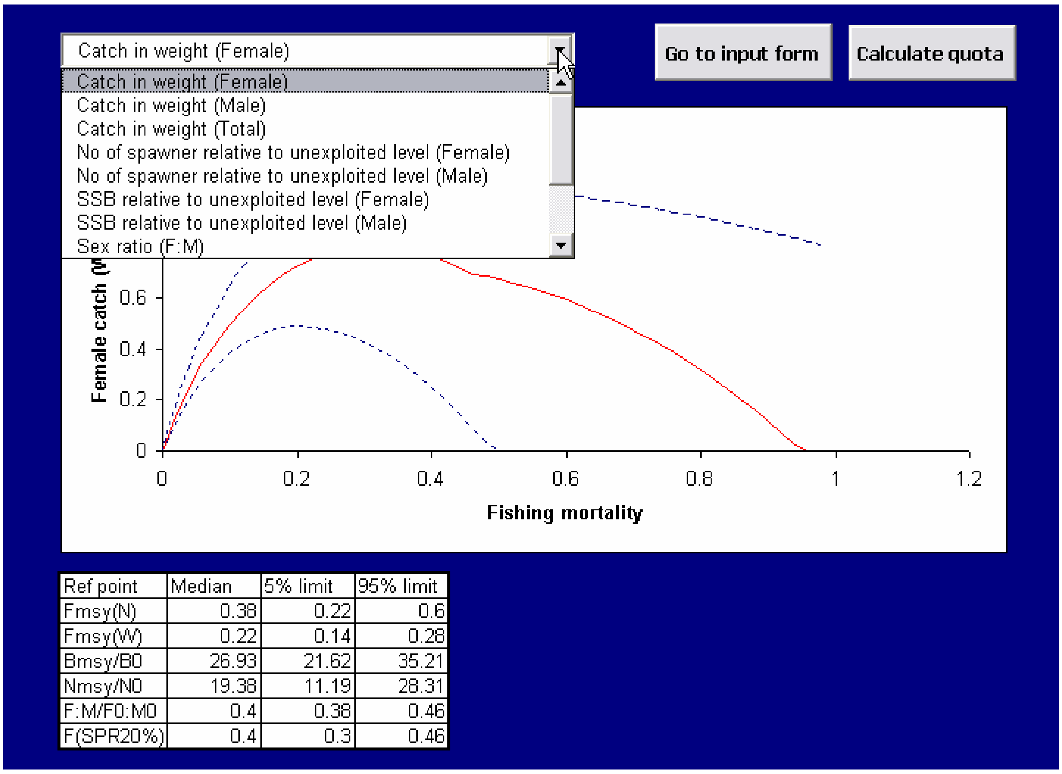


Figure D.11. The progress of model running is indicated through a status bar.

When the calculations have been completed, the results worksheet will be activated while the input forms will be hidden (Figure D.12). There are 12 output types: (1) catch in weight (male), (2) catch in weight (female), (3) catch in weight (total), (4) catch in number (male), (5) catch in number (female), (6) catch in number (total), (7) number of spawners relative to the unexploited level (male), (8) number of spawners relative to the unexploited level (female), (9) spawning stock biomass (SSB) relative to the unexploited level (male), (10) SSB relative to the unexploited level (female), (11) female to male sex ratio, and (12) female:male sex-ratio relative to that in the unexploited state. Each output is plotted against the corresponding fishing mortality rate. An output is chosen from the combo box and the graph for the specified output will be displayed. The solid line represents median values while the broken lines represent the 5 and 95 percentiles.

Six selected reference points are also calculated: (1) fishing mortality rate at Maximum Sustainable Yield (number of animals) ($F_{MSY(N)}$), (2) fishing mortality rate at Maximum Sustainable Yield (biomass) ($F_{MSY(W)}$), (3) ratio of biomass at Maximum Sustainable Yield to unexploited biomass, (4) ratio of abundance (number) at Maximum Sustainable Yield to unexploited abundance (number), (5) sex-ratio (females per male) relative to unexploited level and (6) fishing mortality at which the SSB is 20 percent of that in an unfished state. The median and the 5 and 95 percentiles are displaced under the graph.

Users can return to the input form by clicking the "Go to input form" button from any of the worksheets, then modify the input parameters and re-run the model. Users can restore the input parameters to the default settings (specified in Table 1) by clicking on the button "Restore default". Users can also proceed to calculate a quota by clicking the "calculate quota" option, which will open the quota calculation input form.



Ref point	Median	5% limit	95% limit
Fmsy(N)	0.38	0.22	0.6
Fmsy(W)	0.22	0.14	0.28
Bmsy/B0	26.93	21.62	35.21
Nmsy/N0	19.38	11.19	28.31
F:M/F0:M0	0.4	0.38	0.46
F(SPR20%)	0.4	0.3	0.46

Figure D.12. Outputs from the population model.

Quota calculation

Stock status tab

The parameters that describe the currently available information on abundance and size-structure of the population, as determined by Underwater Visual Surveys are specified in this form. These parameters include the proportion of the total area estimated to be subject to three levels of fishing intensity ("low", "medium" and "high"), the density corresponding to each of these levels, the total reef area and the proportion of reef area that is "at risk" (i.e. areas unable to support Napoleon fish populations because of insufficient habitat – one example would be severely bombed areas). Default values are based on Spalding, Ravilious and Green (2001) (Figure D.13). Users can also view estimates of the six biological reference points on this page. It should be noted that the default that 50 percent of the reefs are unable to support Napoleon fish populations may be subject to discussion/revision, although this parameter can have marked impact on the size of any export quotas.

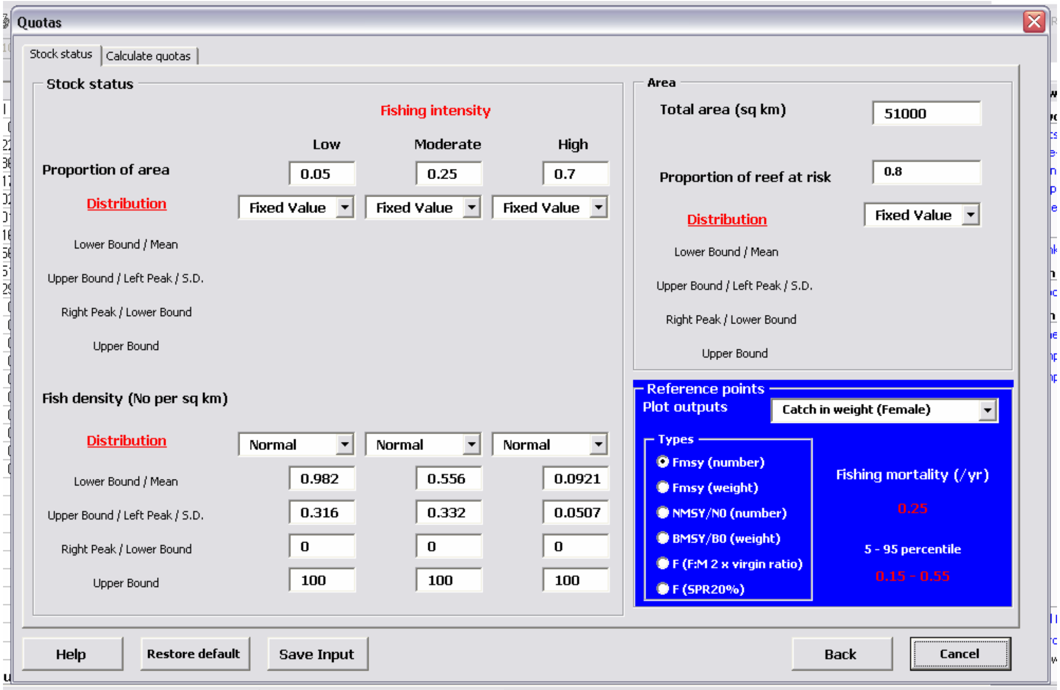
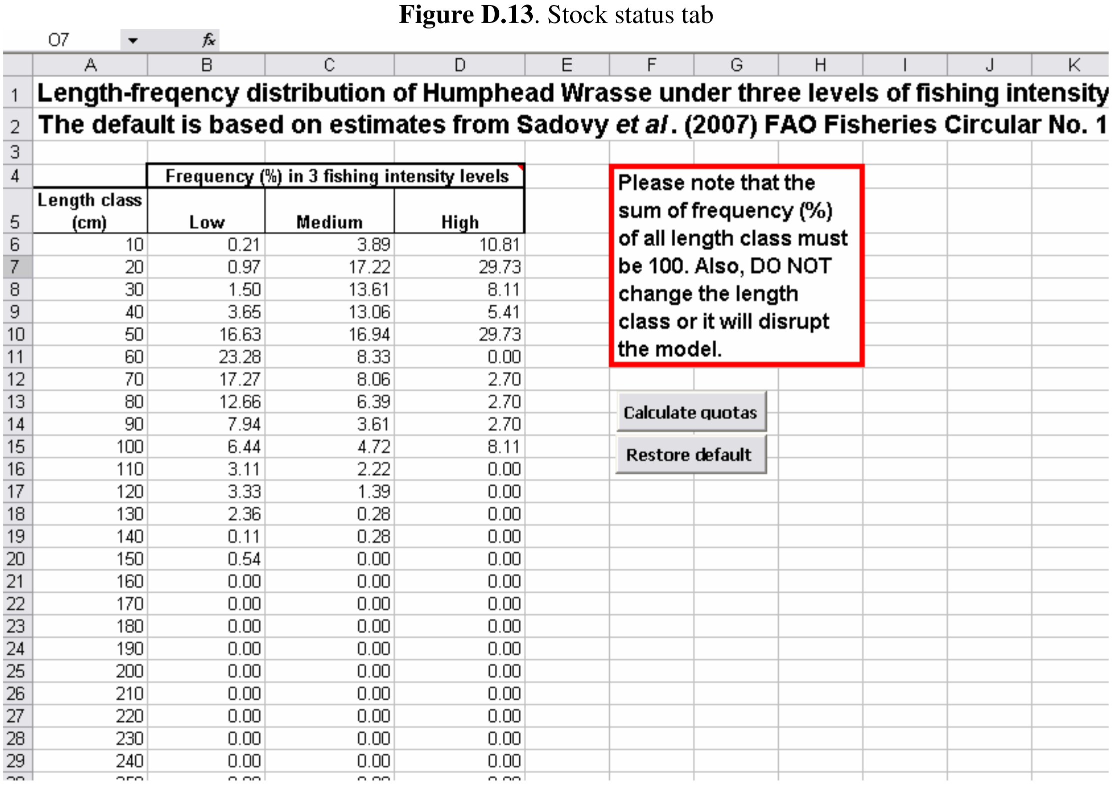


Figure D.13. Stock status tab



Length-freqency distribution of Humphead Wrasse under three levels of fishing intensity

The default is based on estimates from Sadovy *et al*. (2007) FAO Fisheries Circular No. 1

Length class (cm)	Frequency (%) in 3 fishing intensity levels		
	Low	Medium	High
10	0.21	3.89	10.81
20	0.97	17.22	29.73
30	1.50	13.61	8.11
40	3.65	13.06	5.41
50	16.63	16.94	29.73
60	23.28	8.33	0.00
70	17.27	8.06	2.70
80	12.66	6.39	2.70
90	7.94	3.61	2.70
100	6.44	4.72	8.11
110	3.11	2.22	0.00
120	3.33	1.39	0.00
130	2.36	0.28	0.00
140	0.11	0.28	0.00
150	0.54	0.00	0.00
160	0.00	0.00	0.00
170	0.00	0.00	0.00
180	0.00	0.00	0.00
190	0.00	0.00	0.00
200	0.00	0.00	0.00
210	0.00	0.00	0.00
220	0.00	0.00	0.00
230	0.00	0.00	0.00
240	0.00	0.00	0.00

Please note that the sum of frequency (%) of all length class must be 100. Also, DO NOT change the length class or it will disrupt the model.

Calculate quotas

Restore default

Figure D.14. Worksheet that allows users to edit the length-frequency data for the model.

Users are allowed to change the current size-frequency inputs under the three levels of fishing intensity. By clicking on the "Edit length-frequency" button on the Stock status tab, users are directed to a worksheet that contains the default size-frequency data under "low", "medium" and "high" fishing intensity (Figure D.14). Default inputs are based on the analyses of UVS data for Indonesia. Users may enter alternative size-frequency data into the form. However, it is important that the specifications for the length classes remain unchanged. Users can restore the default size-frequencies by clicking on the "Restore default" button. Users can go back to the Calculate quotas form by clicking on the button "Calculate quotas".

Calculate quotas tab

In this form, three parameters: (1) the fraction of the export that is illegal, unregulated and unreported (IUU), (2) the weight of animals used for domestic purposes (non-export), and (3) the mortality rate of the animals after they are caught and before they are exported are specified (Figure D.15). The final estimated export quota will account for these parameters (see Equation 21).

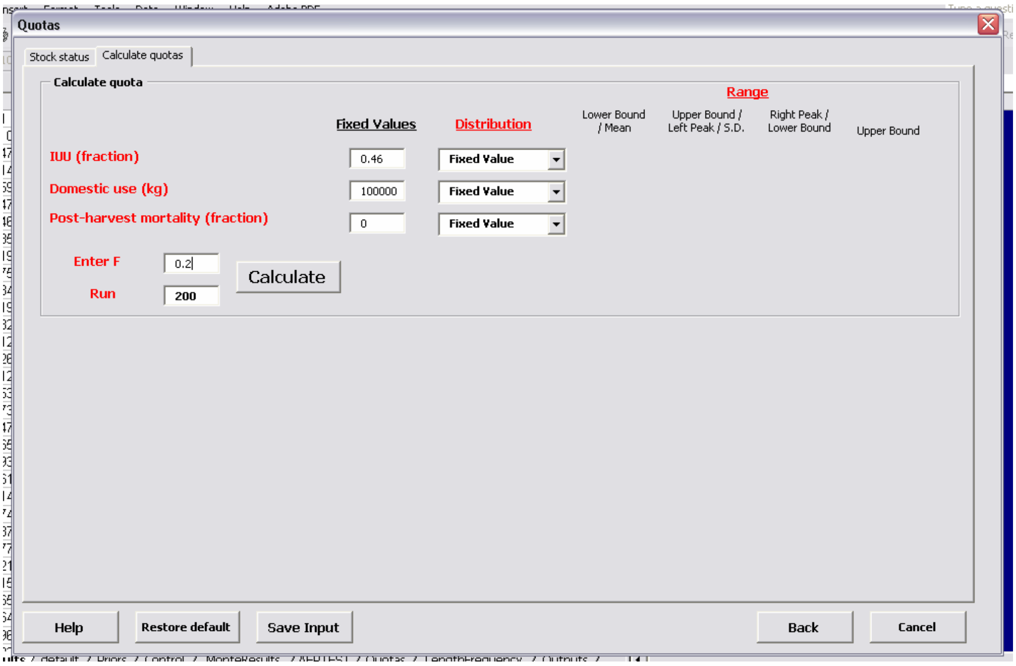


Figure D.15. Calculate quotas tab.

Before running the model, the user must specify the fishing mortality rate for which an export quota is to be calculated. The default fishing mortality rate is the minimum of the best estimates of the fishing mortality rate corresponding to maximum sustainable yield and the fishing mortality rate at which spawning biomass (females) is reduced to 20 percent of its unexploited level. The default setting reflects the need to err on the side of caution given the uncertainty related to biological parameters and abundance (Figure D.15). However, this fishing mortality may still lead to a substantial reduction in spawning biomass and /or a large female bias in the sex-ratio of the spawners. Furthermore, the best estimate may be very imprecise. Users should therefore consider all of the reference points (and their confidence intervals) on the stock status page when deciding on the fishing mortality rate on which to base any quotas. Users can also learn more about the reference points by referring back to the fisheries literature (e.g. Caddy and Mahon, 1995).

The number of Monte Carlo simulation runs should be entered (ideally 200-1000) (Figure D.15). Again, the number of runs depends on the level of uncertainty of the parameters specified by the user. It is recommended that the simulations be repeated with different numbers of runs to roughly identify the optimal number of simulations (i.e. least number of runs so that the estimated quotas do not differ much among runs).

The estimated export quota, which accounts for the domestic consumption and illegal, unreported and unregulated fishing from the estimated total production is displayed on the form (Figure A.16). The outputs of the model also include the estimated stock size in number of animals at present, and the estimated total quota in number of animals with a break-down of the contribution from the wild stock, and grow-out.

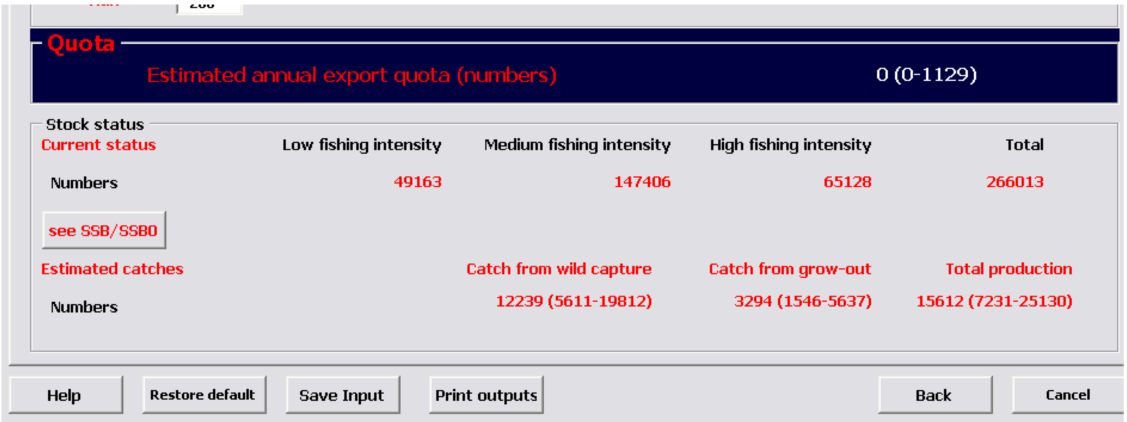
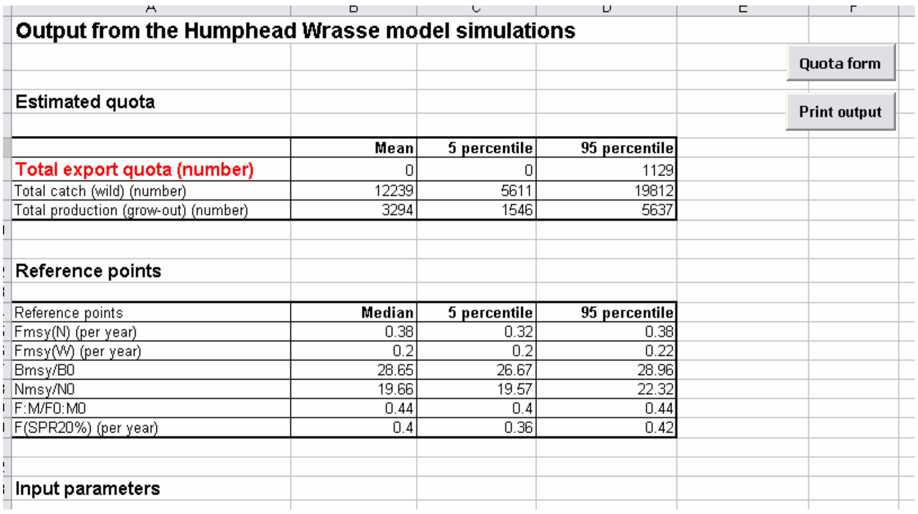


Figure D.16. Estimated export quotas and other outputs from the model

The various outputs, together with the estimated reference points and a summary of all the input parameters, can be viewed from a worksheet by clicking on the "Print output" button (Figure D.17). A worksheet with a table listing the inputs and outputs will be produced. Users can print out the table by clicking on the "Print output" button on the worksheet. Users can go back to the "Calculate quotas" form by clicking on the "Quota form" button.



Output from the Humphead Wrasse model simulations

Quota form

Print output

Estimated quota

	Mean	5 percentile	95 percentile
Total export quota (number)	0	0	1129
Total catch (wild) (number)	12239	5611	19812
Total production (grow-out) (number)	3294	1546	5637

Reference points

Reference points	Median	5 percentile	95 percentile
Fmsy(N) (per year)	0.38	0.32	0.38
Fmsy(W) (per year)	0.2	0.2	0.22
Bmsy/B0	28.65	26.67	28.96
Nmsy/N0	19.66	19.57	22.32
F:M/F0:M0	0.44	0.4	0.44
F(SPR20%) (per year)	0.4	0.36	0.42

Input parameters

Figure D.17. Table summarizing the estimated export quotas, other outputs and the input parameters used in the model.

On the "Calculate quotas" form, users can examine the spawner numbers at the specified fishing mortality rate relative to the unexploited level using a graph by clicking on the "See SSB/SSB0" button (Figure D.18). Users can identify the possible long-term spawner numbers relative to the unexploited level from the vertical broken line which represents the target fishing mortality rate specified in the "Calculate quotas" form.

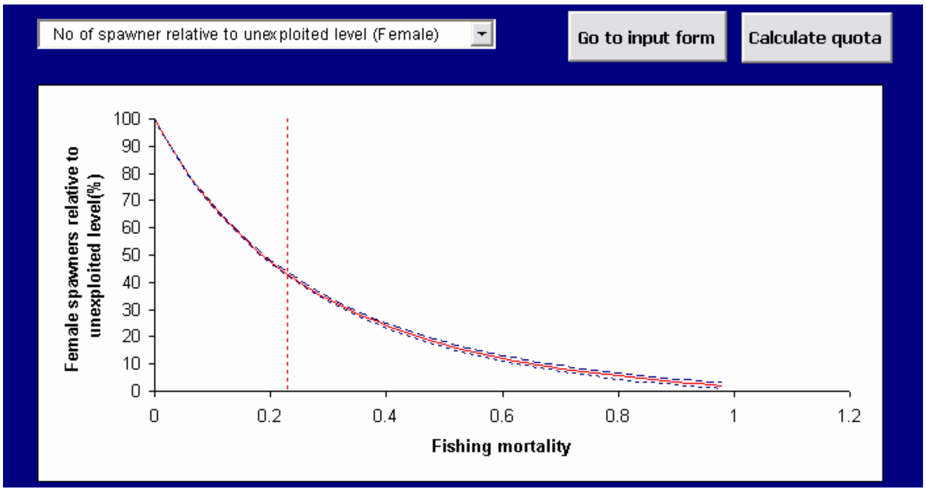


Figure D.18. Figure showing the long-term spawner numbers resulting from the specified fishing mortality rate. The vertical broken line represents the fishing mortality rate specified in the "Calculate quotas" form.

Users can return to the output worksheets by clicking the back button or re-run the model by clicking the "calculate quota" button.

Users can leave the input forms by pressing the "Cancel" button. They can view the detailed outputs from the model in the "MonteResults" and "Quotas" worksheets. The users can copy the output data and store them in a separate spreadsheet to make comparisons between different sets of parameters or to generate figures (other than those provided by the program).

D. 3. Interpreting outputs from model

Population status at different fishing mortality rates and reference points

1. Catch in weight/number
   Calculating the catch (weight or number) corresponding to different fishing mortality rates enables the estimation of Maximum Sustainable Yield (MSY) and the fishing mortality rate that achieves MSY (F_{msy}). MSY refers to the maximum amount of annual catch (in weight or in number) that can be obtained from a stock theoretically over a long period of time. MSY and F_{msy} can be read from the peak of the plot of the relationship between annual catch and fishing mortality. However, achieving MSY may require a substantial reduction of spawning potential or distortion of sex-ratio. Also, the model assumes that environmental conditions are in steady state (constant). In reality, the environment may fluctuate, which may affect the reproductive success of a stock. In cases where spawning potential has been reduced to that corresponding to MSY and the environment becomes unfavorable to the stock, the probability of a stock collapse may be substantially increased. Therefore, setting export quotas to achieve MSY should only be adopted with extreme caution.

2. Spawner abundance/Spawning stock biomass relative to unexploited level
   This indicates the spawning potential (as a function of spawner abundance or spawning stock biomass) under different fishing mortality rates. Spawning potential (percent of spawner abundance relative to the unexploited level) decreases as fishing mortality rates increase. In the model, the fishing mortality rate for which spawner abundance is 20 percent of the unexploited level (spawning potential ratio) is shown. However, in some cases, a 80 percent reduction in spawning potential ratio may be large enough to considerably reduce the reproductive potential of the stock. Therefore, the indicated

reference points should be viewed as guidelines and other reference fishing mortality rates can be selected based on the plot between spawning potential and fishing mortality rate.

3. Sex ratio (female: male)
   Napoleon fish, like other reef fishes, is protogynous (sex-changing from female to male as the fish grows). Therefore, size- or age-selective fishing will distort the sex-ratio of the stock. Spawning potential may be detrimentally affected by a distorted sex-ratio. Therefore, the target fishing mortality rate should be set at a level at which spawning potential is unlikely to be distorted by an unbalanced sex-ratio. The female:male sex-ratio at different fishing mortality rates can be determined from the model outputs and a level of acceptable sex-ratio and its corresponding fishing mortality rate can be determined. Since there are no data on the relationship between fertilization rates and sex-ratios for Napoleon fish, a critical sex ratio of 50 over which fertilization rates will be negatively affected could be used (Petersen *et al.*, 2001).

The export quota calculated using the model is based largely on the specified target level of fishing mortality (see above on reference points) and the current status of the stock. The latter depends on the size range of Napoleon fish in the exporting country, the proportion of reefs "at risk" (assuming that damaged reef is not suitable for Napoleon fish) and the proportion of area corresponding to the three different levels of fishing intensity. The quota also depends on the fraction of the catch from illegal, unreported and unregulated fishing and the amount captured for domestic consumption (thus discounted from the export quota). The estimates of these parameters based on currently available data are given in Appendix B. However, users should consider the default values carefully and collect extra information to fill in data gaps.

Annex I. The labels and the associated help remarks in the user-interface.

Growth tab

Labels	Help remarks
L_{inf}	Asymptotic length (male and female), estimated by fitting the length and age data (grouped by sex) obtained from Choat *et al.* (2006) and the CRC Reef ELF Project (*n*=189 individuals).
von Bertalanffy K	Von Bertalanffy growth parameter *K* (male and female), estimated by fitting the length and age data (grouped by sex) obtained from Choat *et al.* (2006) and the CRC Reef ELF Project with function (*n*=189 individuals).
Variance (growth)	The variance of the growth increment, estimated by fitting the length and age data (grouped by sex) obtained from Choat *et al.* (2006) and the CRC Reef ELF Project (*n*=189 individuals).
Length-weight a	The coefficient *a* of the length-weight relationship: *W=aL^b*. The default value is based on Sadovy *et al.* (2003).
Length-weight b	The coefficient *b* of the length-weight relationship: *W=aL^b*. The default value is based on Sadovy *et al.* (2003).

Reproduction tab

Labels	Help remarks
Gonad-weight *a*	The coefficient *a* of the length-gonad weight relationship: *W=aL^b*. The default value is estimated by re-analyzing the gonad weight – fork length data (n=115) from Choat *et al.* (2006). The updated analysis fits the length-gonad weight relationship to the data for resting or immature animals and to the data for ripe animals separately.
Gonad-weight *b*	The coefficient *b* of the length-gonad weight relationship: *W=aL^b*.
Natural mortality (Wild)	Instantaneous natural mortality rate (*M*) for animals living in the wild. *M* was estimated by regressing the logarithm of age-frequency on age and then subtracting the rate of fishing mortality. Based on data from Choat *et al.* (2006), *M* was estimated to be 0.106 yr^{-1} (+/- 0.022).
Rate of sex-change	The rate at which animals change from female to male, assumed to lie between 0.04 and 0.27 yr^{-1}.
Lowest length at maturity	The minimum length at which mature animals are observed. Based on the data from Sadovy *et al.* (2003) and the Great Barrier Reef (Bruce Mapstone, pers. comm.), no fish smaller than 35 cm were found to be mature. Therefore, the lowest length at maturity is assumed to be 35 cm.
Length at 50% maturity	The length at which 50% of animals are mature, assumed to be 35 cm. This is because available data on maturity-at-length and field observations showed that Napoleon fish do not reach maturity before 35 cm TL.
Length at 95% maturity	The length at which 95% of animals are mature. Based on data from Sadovy *et al.* (2003) and the Great Barrier Reef (Bruce Mapstone, personal communication), length at 95% maturity was estimated by fitting the maturity data above 35 cm TL using a logistic function.

Reproduction tab con't

Labels	Help remarks
Smallest size at sex-change	The minimum size at which an animal changes from female to male. Based on available data on size at sex change for the species, sex change is predicted to occur between 55 and 75 cm (Choat *et al.*, 2006).
Largest size at sex-change	Largest size at which females change sex to male. Based on available data on size at sex change for the species, sex change is assumed to occur between 55 and 75 cm (Choat *et al.*, 2006).

Recruitment tab

Labels	Help remarks
Steepness	The fraction of the total number of age-0 animals that occur in the absence of fishing that is expected when the spawning biomass (female gonad weight) is reduced to 20% of that in the absence of fishing. The steepness parameter partly determines the stock-recruitment function. Specifically, it determines the rate of recruitment when population size is greatly reduced and affects the recovery rate of the population. There are insufficient data to estimate the steepness of the stock-recruitment relationship for Napoleon fish. Thus, a Bayesian hierarchical meta-analysis was conducted for steepness using stock and recruitment data for 12 coral reef-associated fishes. This meta-analysis indicated that steepness for coral reef fishes was likely to be less than for typical temperate teleost species (i.e. coral reef fishes are less resilient to reductions in spawning biomass than many temperate marine teleosts). The logit of steepness is assumed to be normally distributed for input into the model.
Check to specific the possible impacts of sex-ratio imbalance on recruitment	Check this box to specify the possible impacts of sex-ratio imbalance on recruitment. With the current knowledge, such impacts on Napoleon fish are not clear. Therefore, this option is not activated in the default settings.
Sex-ratio impact rate	The parameter that determines how rapidly fertilization rates decline with increasing sex-ratio. There is no information on the impact of sex-ratio on recruitment success for Napoleon fish so the default value for this parameter is 0 (i.e. no impact). However, the value for this parameter could be changed given the results of additional research.
Critical sex-ratio	The critical female to male sex ratio above which fertilization rates decline. Since there are no data on the relationship between fertilization rates and sex-ratios for Napoleon fish, relevant data from the related bluehead wrasse are used to provide the base-line value for a critical sex ratio of 50 females to 1 male (Petersen *et al.*, 2001).

Fisheries and grow-out tab

Labels	Help remarks
Selectivity	Gear selectivity by size is assumed to be the sum of a constant and a lognormal density. The length-at-modal selectivity and the variance of the selectivity function, and the constant term, determine the shape of the selectivity ogive. The default values for the parameters of the selectivity function are determined by fitting it to data on selectivity as a function of length. The data on selectivity are the ratios of the length-frequency data from surveys of live reef food fish retail and wholesale markets in China, Hong Kong SAR, divided by the population length-frequency inferred from the UVS data.
Check to include grow-out production i.e. putting wild animals into culture facilities and growing them on until marketable/saleable size	Check if there is grow-out (i.e., putting wild animals into culture facilities and raising them to marketable size). This is important because natural mortality and growth rates in culture facilities can differ from wild fish.
Natural mortality (Cages)	Instantaneous rate of mortality for animals being kept in grow-out facilities. A total of 26 collectors were surveyed, of which 18 provided information on the duration of grow-out in cages, the mortality rate (fraction dying while in cages) and the numbers collected (Sachoemar, Suharti and Sadovy, 2006). The estimate of grow-out mortality was determined by a weighted sum of the mortality rates by collector (range 0-80% over periods in cages ranging from 1 to 48 months), weighting the mortality rate (expressed as an annual rate) by the number collected. The resulting estimate of the annual mortality rate in cages is 0.134 /year (bootstrap SD = 0.064 /year).
Length-at-export	The minimum length at which animals from grow-out facilities are exported, on average. A total of 26 collectors were surveyed, of which 18 provided information on the duration of grow-out in cages, the mortality rate (fraction dying while in cages) and the numbers collected (Sachoemar, Suharti and Sadovy, 2006). The sizes of animals received for grow out ranged from 5-30 cm. This forms the basis for the assumed default value.
Length-50%-export	The length at which 50% of the animals caught are directly exported without being placed in grow-out cages. A total of 26 collectors were surveyed, of which 18 provided information on the duration of grow-out in cages, the mortality rate (fraction dying while in cages) and the numbers collected (Sachoemar, Suharti and Sadovy, 2006). The sizes of animals received for grow out ranged from 5-30 cm (total length). This forms the basis for the assumed default value.

Run model tab

Labels	Help remarks
Number of runs	The number of Monte Carlo runs required depends on the levels of uncertainty that are specified by the user for each parameter. The more uncertain the parameters (for instance, uniform distributions with wide ranges), the more Monte Carlo runs are required to allow the results to converge. On the other hand, every Monte Carlo run would lead to the same results if no uncertainty is specified (i.e. fixed values are used for every parameter). Based on sensitivity analysis, a minimum of 200 runs is recommended.
F step	This is the fishing mortality (year $^{-1}$) interval for the simulation. Smaller F intervals increase the resolution of the simulation, but also increase computation time. F steps of no less than 0.1 year $^{-1}$ are recommended.
F range	The range of fishing mortality rates (year $^{-}$1) that will be examined during the simulations.

Stock status tab

Labels	Help remarks
Fishing intensity	Fishing intensity on reefs was categorized into 3 levels; **low, medium, high**. Qualitative criteria were used to assign the intensity levels. Information was obtained from interviews with fishermen, underwater surveys, observation of catches, discussions with knowledgeable fishery officers, referral to fishery reports from the area, questionnaires, demographic data, etc. The default intensities were also partly determined by consultation at a workshop on Napoleon fish with Indonesian fisheries officers held in Jakarta (3 Nov 2006). Please refer to Table 6 for details. Note that fish densities at different levels of fishing intensity and the percentage of reef subjected to different levels of fishing pressure will vary nationally.
Proportion of reef area	Proportion of reef area exposed to each of the three levels of fishing intensity. If you choose to specify a fixed value, please make sure that the proportion of reef area for the three fishing intensity levels sum to 1 (i.e., all reefs, or 100%, must be accounted for)
Total area (sq km)	The total reef area in Indonesia is assumed to be about 51 000 square km (Spalding, Ravilious and Green, 2001), based on the most widely accepted standard currently available. However, this estimate is under revision using a more advanced methodology and revisions to country reef areas will be provided subsequently.

Calculate quotas tab

Labels	Help remarks
IUU (fraction)	This is the proportion of animals caught from Illegal, Unreported or Unregulated (IUU) fishing. A default value for the amount of IUU was calculated (roughly) using import data from China, Hong Kong SAR, and export records. The import data from China, Hong Kong SAR, include imports by air (from China, Hong Kong SAR, Census and Statistic Department or CSD) and by sea (from China, Hong Kong SAR, Agriculture, Fisheries and Conservation Department or AFCD). Assuming a proportion of import by sea from the exporting country (e.g. conservatively assumed 50% for Indonesia), total import to China, Hong Kong SAR, can be calculated. The amount of IUU and the proportion of IUU to total catch can be estimated from the difference between the legal export and the total import. The default value is an estimate for Indonesia (Appendix B).
Domestic use (kg)	This is the total weight in kg of animals that are for domestic consumption. For example, the domestic catch of humphead wrasse reported by the Government of Indonesia to FAO for 2004 and 2005 was 115 t and 100 t, respectively. Thus domestic use was estimated as 100 000 kg (default value in the model) (Appendix B).
Post-harvest mortality (fraction)	This is the mortality of the animals after capture, but before being exported or sold in the market.
Enter F	The default fishing mortality rate (year $^{-1}$) is the minimum of the best estimates of the fishing mortality rates corresponding to maximum sustainable yield and the fishing mortality at which the spawner abundance is 20% of that in an unfished state.
Run	The number of Monte Carlo runs required depends on the levels of uncertainty that are specified by the users for each parameter. The more uncertain the parameters (for instance, uniform distribution with wide range of lower and upper bounds), the more Monte Carlo runs are required to allow the solutions to converge. On the other hand, if no uncertainty is specified (i.e. fixed values are used for every parameters), every Monte Carlo run would give the same solution. Based on sensitivity analysis, minimum of 200 runs are recommended for default settings.
Current status	The current stock status based on the specified density by fishing intensity, total area, and proportion of area at risk. The values in parenthesis show 5 and 95 percentiles.
Estimated catches	This is the estimated catch based on the chosen fishing mortality rate. The total catch is different from the estimated export quota because part of the catch is assumed to be consumed locally, exported illegally (thus not part of the export quota) or lost due to post-harvest mortality but before export.
Catch from wild capture	Estimated catch from the wild given the specified fishing mortality rate. The values in parenthesis show 5 and 95 percentiles.
Catch from grow-out	Estimated production from grow-out. The values in parenthesis show 5 and 95 percentiles.
Total production	Estimated amount of total production including wild capture (reported and IUU), grow-out and domestic consumption.

AUTHOR BIOGRAPHIES

Yvonne Sadovy

Yvonne Sadovy is a Professor and has been with the Department of Ecology & Biodiversity, University of Hong Kong since 1993, where she is currently Head. Prior to this position, she was Director of the Fisheries Research Laboratory of the government of Puerto Rico and worked as a fisheries biologist for the Caribbean Fishery Management Council on which she also held a position on the Scientific Advisory Committee during the 1990s. She holds a PhD in Zoology from the University of Manchester (1986) and is also the Chair (since 1998) of the IUCN Specialist Group for Groupers and Wrasses (Serranidae and Labridae).

Dr Sadovy has published two co-authored books and has over 100 other outputs, most of which are peer-reviewed and in international journals. Her speciality is in reef fishes, especially their reproductive biology, and age and growth, and in the conservation and management of vulnerable fish species. She has worked extensively in the field in the tropics and has broad in-water and laboratory experience. Dr Sadovy is on the Editorial Boards of Journal of Fish Biology, Conservation Biology, Fish and Fisheries, and Reviews in Fish Biology and Fisheries.

André Punt

André Punt is an Associate Professor with the School of Aquatic and Fisheries Sciences, University of Washington, Seattle. Prior to this he was a Senior Research Scientist with CSIRO Marine Research in Hobart, Australia. He holds an M.Sc. and a Ph.D. in Applied Mathematics from the University of Cape Town, South Africa. André has been involved in research on marine population dynamics, stock assessment methods, and harvesting theory since 1986, and has published over 100 papers in the peer-reviewed literature along with over 300 technical reports. His current research focuses on the performance of stock assessment methods, application of Bayesian approaches in fisheries assessment and decision analysis, and management strategies for fish and marine mammal populations. He is a member of the American Fisheries Society and the Australian Society for Fish Biology. In 1999, he became the third recipient of the K. Radway Allen Award, awarded by the Australian Society of Fish Biology for "an outstanding contribution in fish or fisheries science".

Until early 2000, when he left Australia to join the University of Washington, André was chair of Australia's Southern Shark Fishery Assessment Group and a member of the Shark Fishery Management Advisory Committee. He has been a member of several other stock assessment teams in South Africa, Australia, New Zealand and the U.S. He is currently an at-large member of the Scientific and Statistics Committee of the Pacific Fisheries Management Council. He is also a member of the IUCN Shark Specialist Group, participated in the review of the IUCN criteria for listing species at risk of extinction, and is currently a member of the IUCN Red List Standards and Petitions Working Group.

André has participated in the Scientific Committees of the International Commission for the South East Atlantic Fisheries (ICSEAF) and the International Commission for the Conservation of Atlantic Tunas (ICCAT). He has been an invited participant to the Scientific Committee of the International Whaling Commission (IWC) since 1990. He is currently a member of the Editorial Boards of the journals "Fisheries Research", "Journal of Applied Ecology" and "Population Ecology".

William Cheung

William (Wai Lung) Cheung is a postdoctoral fellow at the Fisheries Centre, University of British Columbia. His research interests include ecosystem modelling, studying vulnerability of marine fish and its implications to fishery management. William obtained a BSc. (Biology) in 1998, and subsequently a M.Phil. in 2001 from the University of Hong Kong and a Ph. D. in 2007 from the University of British Columbia.. His master research focused on the use of local and traditional knowledge in understanding the change in fisheries and marine ecosystem in China, Hong Kong SAR. After finishing his master degree, he joined the World Wide Fund For Nature (WWF) China, Hong Kong SAR, as an Assistant Conservation Officer. Over the two years in WWF, William's works focused on local and regional marine conservation policy study and advocacy, environmental impact assessment, and involved in environmental education. He has published a number of peer-reviewed papers and technical reports. Besides, he served as member in the advisory group on fisheries management for the China, Hong Kong SAR government, and was an executive committee member of the Hong Kong Marine Conservation Society. He is a member of the IUCN Specialist Group for Groupers and Wrasses (since 2005).

Marcelo Vasconcellos
Marcelo Vasconcellos is a Fishery Resources Officer at the Food and Agriculture Organization of the United Nations (FAO). Marcelo is trained in biological oceanography and holds his PhD from the University of British Columbia in resource management and environmental studies. Before working for FAO, Marcelo worked as Research Associate at the Department of Oceanography, University of Rio Grande, Brazil, and at the Fisheries Centre, University of British Columbia. One of the central themes of his research has been the development of ecosystem approaches to fisheries assessment and management. At FAO, he is currently responsible for the implementation of trust fund projects related to "Capacity building for an ecosystem approach to fisheries" and to "CITES and commercially-exploited aquatic species".

Sasanti Suharti
Sasanti Suharti is a researcher in the Research Center for Oceanography, Indonesian Institute of Sciences. She has been working since 1987. She graduated from National University, Jakarta, Indonesia in 1986 and she holds a Master's degree in Marine Biology from James Cook University of North Queensland, Australia in 1995. She works mainly on coral reef fishes in tropical waters, in addition to work on ichthyoplankton, seagrass and mangrove fishes. Sasanti conducted bilateral research collaborations with the Japan Society of Promotion of Science (JSPS) from 1995–2000, and has been involved in the JSPS Multilateral Cooperative Research Program on Marine Science since 2001 under its Biodiversity Project.

Bruce Mapstone
Bruce Mapstone is a Professor at the University of Tasmania and Chief Executive Officer of the Antarctic Climate & Ecosystems Cooperative Research Centre, based at the University of Tasmania. He was previously a Senior Principle Research Fellow at James Cook University in Townsville, Program Leader of the Sustainable Industries Program in the CRC for the Great Barrier Reef World Heritage Area (CRC Reef) and CEO designate of the CRC Torres Strait. He founded and led the Effects of Line Fishing Project and later the Fishing and Fisheries Project at the CRC Reef from 1993–2003. His research interests include environmental impact assessment, fisheries dynamics, impacts and management and the use of Marine Protected Areas for managing marine resources and he has a strong interest in delivering research outputs to stakeholders beyond the traditional research peer communities. He has published one book and over 60 refereed articles and monographs on marine ecology, statistical inference, environmental impact assessment and monitoring, tropical fisheries, fisheries management and Marine Protected Areas. Bruce has chaired or served on many advisory committees to the Australian or state governments, mainly related to fisheries management, the Great Barrier Reef, National Regional Marine Planning, and Marine Protected Area planning. Bruce received his PhD from the University of Sydney in 1989.

ISBN 978-92-5-105775-9 ISSN 0429-9329

TR/D/A1237E/1/08.07/500