USING LIFE-HISTORY, SURPLUS PRODUCTION, AND INDIVIDUAL-BASED POPULATION MODELS FOR STOCK ASSESSMENT OF DATA-POOR STOCKS: AN APPLICATION TO SMALL PELAGIC FISHERIES OF THE LINGAYEN GULF, PHILIPPINES

A Thesis

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TO MY SISTER REMELY

YOU WILL ALWAYS BE MY INSPIRATION.

THANK YOU FOR ALL THE SACRIFICES, LOVE, AND UNDERSTANDING.

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ABSTRACT

Stock assessment methods that quantify the status of fishery resources are critical to effective fisheries management. There is a need for stock assessment methods applicable for management of tropical species based on limited, un-aged catch data. I applied four stock assessment approaches to situation with limited life-history information and with short-term, un-aged catch data. The four approaches are: life-history invariants, length-based catch analysis, individual-based modeling, and surplus production modeling. All four approaches were applied to catch data from Lingayen Gulf, Philippines. The life-history invariant, length-based catch analysis, and individual-based modeling were applied to monthly length-frequency data of commercial catch for each of the three commonly caught species (moonfish, short mackerel, and tropical anchovy); surplus production modeling was applied to total annual catch and effort (all species combined) of commercial and municipal fisheries. Catch data was analyzed to determine current fishing mortality rate ($F_{current}$). The stock assessment approaches were used to compute the fundamental stock assessment benchmark of fishing mortality rate at MSY (F_{msy}). Comparison of $F_{current}$ to F_{msy} provides critical information on sustainability of current harvest rates. The application of surplus production modeling resulted in questionable parameter estimates but did suggest that $F_{current}$ have been increasing. The results using life-history invariant, length-based catch analysis, and individual-based modeling methods predicted that $F_{current}$ of moonfish and short mackerel likely were or exceeded F_{msy} values. Estimated $F_{current}$ of tropical anchovy were lower than the other species and lower than the estimated F_{msy} values, but the harvesting of many juveniles and the increasing fishing rates also make their status worth monitoring. I discuss the use of multiple approaches and year-specific analyses to bound the high uncertainty associated with the reliance of all of the species-specific methods on accurate identification of cohorts from the length-frequency catch data and other assumptions. The use of multiple methods and approaches to estimate and compare $F_{current}$ to F_{msy} provided relatively higher degree of confidence in the results. I conclude with the implications of my results to the management of pelagic fisheries in Lingayen Gulf – namely that harvesting rates of moonfish and short mackerel should be reduced from current levels.

1. INTRODUCTION

1.1. Fisheries and Stock Assessment

Fishes of the world's oceans were once considered inexhaustible (Safina 1995; Pauly and Palomares 2005), and that human fishing could not deplete widely dispersed marine fish populations (Haddon 2001). Times have changed and there is now a crisis looming as humans witness the collapse of fisheries, destabilization of marine ecosystems, decreasing biodiversity, and increasing impoverishment of coastal communities (Pauly et al. 1998; Watson and Pauly 2001; Myers and Worm 2003; Hilborn 2001; Hutchings and Reynolds 2004). The large number of overfished populations (Jackson et al. 2001; Garcia and Grainger 2005; Froese 2004; Fulton et al. 2005), as well as indirect effects of fisheries on marine ecosystems (Myers and Worm 2005), indicate that fisheries management has failed to achieve its principal goal of sustainability (Botsford et al. 1997; Jackson et al. 2001).

Practicable methods for quantifying the status of fishery resources are critical to effective fisheries management (Gobert 1997; Aubone 2003). Stock assessment methods determine changes in the abundance of fishery stocks in response to fishing, and predict future trends of stock abundance. Stock assessment involves collecting and analyzing biological and statistical information based on resource surveys, knowledge of habitat, life-history, and behavior of the species, and catch data. Stock assessments are used as a basis to assess and specify the present and probable future condition of a fishery (NOAA 2005).

Mathematical models that underlie stock assessment have been developed to provide scientifically sound information on stock status and on predicted harvesting rates relative to sustainable harvest rates (Sissenwine 1981). Stock assessment models have been used to provide predictions of annual yields into the future under different harvest strategies, short-term yield forecasts, recommendations of allowable biological catch, and evaluation of the feasibility of stock rebuilding strategies (Rose and Cowan 2003). The results of these mathematical models form the basis of recommendations to fishery management agencies, which subsequently formulate management plans and strategies to ensure the sustainable and optimal use of the resource (Cadrin 1999; Caddy 2002; Hilborn 2001). Stock assessment models typically involve the use of life-history information on growth, mortality, and reproduction, coupled with indices of stock abundance derived from commercial fisheries data or scientific surveys (Gayanilo and Pauly 1997; Beddington and Kirkwood 2005).

While there has been much research in the area of stock assessment (Hilborn and Walters 1992), most effort has focused on temperate species and on situations where relatively long-term, age-based data are available. Commonly used methods include virtual population analysis (Gayanilo and Pauly 1997; Haddon 2001) and age-structured matrix projection models (Hilborn and Walters 1992; Quinn and Deriso 1999). These methods generally use catch or survey data, from which individuals have been sampled and their size (length or weight) measured and their age determined from hard-parts such as scales or otoliths (Gallucci et al.1996; Gayanilo and Pauly 1997; Quinn and Deriso 1999). While age-structured approaches provide a powerful framework for stock assessment, determination of ages is labor intensive, involves high costs and capital investment, and requires well-trained personnel (Craig 1999; Pilling 1999).

Developing countries are often faced with limited historical data and with recent data that show what appear to be high or increasing harvest rates. There is usually only limited knowledge of the life-history of the species (Gobert 1997), and harvested individuals are often sized but not aged. There is a need for stock assessment models applicable for management of tropical species based on limited, un-aged catch data (Garcia and Grainger 1989; Gobert 1997).

Length-based stock assessment methods were developed for species for which it is difficult to obtain accurate ages (Gayanilo and Pauly 1997; Froese and Binohlan 2003). This class of methods relies on length-frequency data that are cheap and relatively easy to obtain (Pauly 1984; Gulland and Rosenberg 1992; Gallucci et al. 1996; Gayanilo and Pauly 1997). The principle is the same as with the age-based methods, whereby length-based methods make use of very similar assumptions about how a fish population behaves and responds to harvesting (Gulland and Rosenberg 1992). Some of the commonly used length-based methods, such as ELEFAN (Gayanilo and Pauly 1997), are available in computer packages to enable their easy use by non-modelers. Examples of these computer packages are FiSAT (Fish Stock Assessment Tool, Gayanilo et al. 2002), and LFDA (Length Frequency Distribution Analysis, Froese and Pauly 2006).

The objective of this study was to evaluate the feasibility of applying commonly used stock assessment approaches to situations with limited life-history information and with short-term, un-aged catch data. The four approaches I applied are denoted as: life-history invariants, length-based catch analysis, individual-based population modeling, and surplus production modeling. All four of these approaches were applied to catch data from the Lingayen Gulf located in the Philippines. The life-history invariant, length-based catch analysis, and individual-based modeling were applied to monthly commercial catch of each of the three commonly caught species (moonfish, short mackerel, and tropical anchovy); surplus production modeling was applied to total annual catch and effort (all species combined) of the commercial and the municipal fisheries. Catch data were analyzed to determine the current fishing mortality rate ($F_{current}$). The stock assessment approaches were used to compute the fundamental stock assessment benchmark of the fishing mortality rate at maximum sustainable yield (F_{msy}). Comparison of $F_{current}$ to F_{msy} provides critical information on the sustainability of current harvest rates. Results should allow for both specific advice for the management of the commercial fisheries of the Lingayen Gulf, Philippines, and more general advice of how to apply stock assessment methods to data-poor stocks.

1.2 Site Description and Fisheries

1.2.1 Lingayen Gulf and Its Fisheries

The Lingayen Gulf is a semi-enclosed body of water with an area of 2,100 km^2 located in the northern Philippines (Figure 1). Two provinces and 18 coastal municipalities surround the Lingayen Gulf. Coral reefs line the western side of the Lingayen Gulf, and white sandy beaches dominate the eastern portion. Lingayen Gulf is considered one of the major fishing grounds of the Philippines (McManus and Chua1990; Talaue-McManus et al. 2001). The Lingayen Gulf is an important source of jobs, income, and food for the surrounding coastal communities.

There are two types of fisheries in Lingayen Gulf: municipal and commercial. The municipal fisheries are sometimes referred to as artisanal fisheries. These are typically traditional fisheries involving fishing households that use relatively small

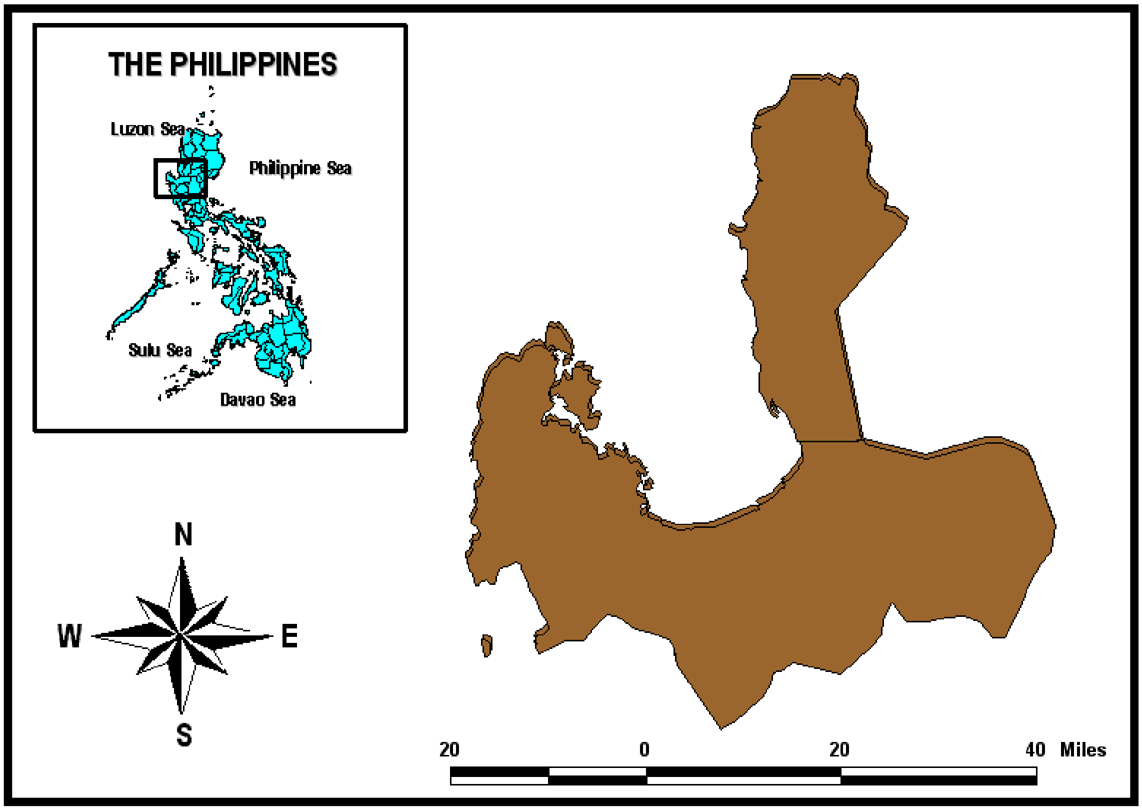
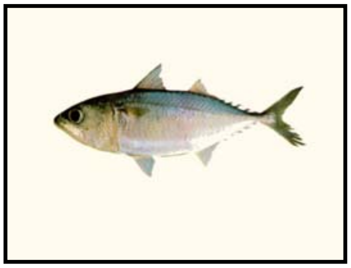


Figure 1. Map showing the Lingayen Gulf, Philippines.

amount of capital. Strictly, the municipal fisheries use fishing vessels of three gross tons or less, they make short fishing trips that are close to shore, and the harvest is mainly for local consumption. The commercial fisheries use fishing vessels weighing greater than three gross tons, and catch fish for trade or profit beyond subsistence or sports fishing (RA 8550).

Small pelagic species are the most dominant fisheries in Lingayen Gulf. These species are harvested by trawling, and the fisheries provide about one-half of the incomes of the nearby coastal communities (Ochavillo et al. 1991). The moonfish (*Mene maculata*), short mackerel (*Rastrelliger brachysoma*) and tropical anchovy (*Stolephorus commersonii*) dominate the catch of small pelagic fishes (Figure 2), and typically

Sn: ***Mene maculata***
En: moonfish



Sn: ***Rastrelliger brachysoma***
En: short mackerel

Sn: ***Stolephorus commersonii***
En: tropical anchovy

Figure 2. Three small pelagic fish commonly harvested by commercial fisheries in the Lingayen Gulf, Philippines.

comprise about 70% of the total annual catch in the Lingayen Gulf commercial fisheries. Spawning seasons for these three species span March through early October (Ochavillo et al. 1991; Froese and Pauly 2006). Significant spawning occurs during August to September that coincides with the rainy season when water temperatures are 25 to 30 ^{o}C and primary production is high. Matching of spawning with good environmental conditions should encourage larval survival (Cushing 1990; Durant et al. 2005). Fishing activity is also reduced during the peak spawning periods due to prevalent tropical storms during the rainy season, which tends to allow the fish to spawn before they are harvested.

All three species live about 4-5 years, exhibit fast growth, early maturation, release multiple batches of eggs over a long spawning season, and feed almost exclusively on zooplankton throughout their life (Dalzell 1988; Fréon et al. 2005). According to the Winemiller and Rose (1992) three end-point life-history surface, these three species would be categorized as opportunistic strategists. With an exception of upwelling systems (e.g., Barrett et al. 1985; Bertrand et al. 2004), there is relatively little information available about the life history and recruitment of opportunistic strategists because harvest in the temperate areas are more focused on the longer-lived, high-fecundity periodic strategists (Rose et al. 2001; Winemiller 2005). These three species serve as excellent reference species for determining the impact of current commercial fishing rates on small pelagic species in the Lingayen Gulf.

1.2.2. Fisheries Management

Numerous conservation and management projects have been implemented to address issues related to the sustainable harvest of fisheries resources of the Lingayen Gulf. Past projects include the Lingayen Gulf Coastal Management Project, the Community-based Coastal Resource Management Project, and the Community-based Natural Resource Management Project. A major current initiative designed to address fisheries issues in Lingayen Gulf is the Fisheries Resource Management Project (FRMP), and is co-financed by the Asian Development Bank and the Japan Bank for International Cooperation. The FRMP addresses two critical and interconnected issues: possible overharvesting and persistent poverty among municipal fishers. The FRMP emphasizes fisheries resource protection and conservation through sustainable management, and encourages the involvement of local fishers in the management process (e.g., community-based management approaches).

Policy and legislation related to the use of Lingayen Gulf spans over 70 years (DENR et al. 2001), beginning with the enactment of the first Fisheries Act in 1932. In the past, coastal fisheries were managed under the assumption that there was limited demand for what were then considered an unlimited supply of economically valuable fish. Fisheries were treated as open-access and were relatively unmanaged (DENR et al. 2001; Green et al. 2003; Silvestre and Pauly 2004). The passing of Fisheries Decree of 1975 (PD 704), with its emphasis on harvesting, did not slow the expanding commercial fishing industry. Management-related restrictions were limited, and penalties for violations were light.

In 1991, the Local Government Code (LGC) was enacted. The LGC caused a structural shift in power that placed coastal local government and cities at the forefront of sustainable resource management. The LGC granted jurisdiction of municipal waters to local government units (LGUs). The LGC provides the institutional framework for a decentralized management of coastal resources and encourages citizens and NGOs to actively participate in coastal resource management efforts. However, even after the enactment of the LGC, commercial and municipal fisheries in the Lingayen Gulf continued to expand.

The recent enactment (1992) of the Republic Act 7586, better known as the National Integrated Protected Area System (NIPAS), also has implications for fisheries management. The NIPAS is a national system of classification and administration of all designated protected areas to maintain essential ecological processes, preserve genetic diversity, ensure sustainable use of resources, and to maintain their natural conditions to the greatest extent possible. The NIPAS provides for the conservation of ecologically important seascapes and coastal areas. The law is important to fisheries management as it includes marine protected areas as a tool for conservation and management of marine biodiversity (DENR et al. 2001).

Most recently, the Fisheries Code of 1998 (RA 8550), which replaced the Fisheries Decree of 1975 (PD 704), was enacted. The focus of the Fisheries Code of 1998 is on addressing food security and on integrated coastal area management; the Fisheries Code lays the groundwork for limiting access to the fisheries. The Fisheries Code establishes a fishing license and permit system based on the concept of maximum sustainable yield (MSY), and allows for limits on harvest via gear restrictions (e.g., no trawling in municipal waters), limited access (e.g., closed seasons and closed areas), and the establishment of fish refuges and sanctuaries. The new law also highlights the preferential rights of subsistence fishers over the commercial fishers.

1.3 Data Description

Length-frequency (Figure 3) and catch data (Figure 4) of moonfish, short mackerel and tropical anchovy were obtained from the three commercial fish landing areas in the Lingayen Gulf. The data were collected for 5 years from 1998 to 2003 as part of the National Stock Assessment Project (NSAP) of the Philippine Bureau of Fisheries and Aquatic Resources (BFAR). Collection of data was done every third day regardless of Saturdays, Sundays and holidays, using the method proposed by Gayanillo and Pauly (1997). Length-frequency data was summed to obtain monthly values for my analyses using the life-history invariants, length-based catch analysis, and individual-based population modeling.

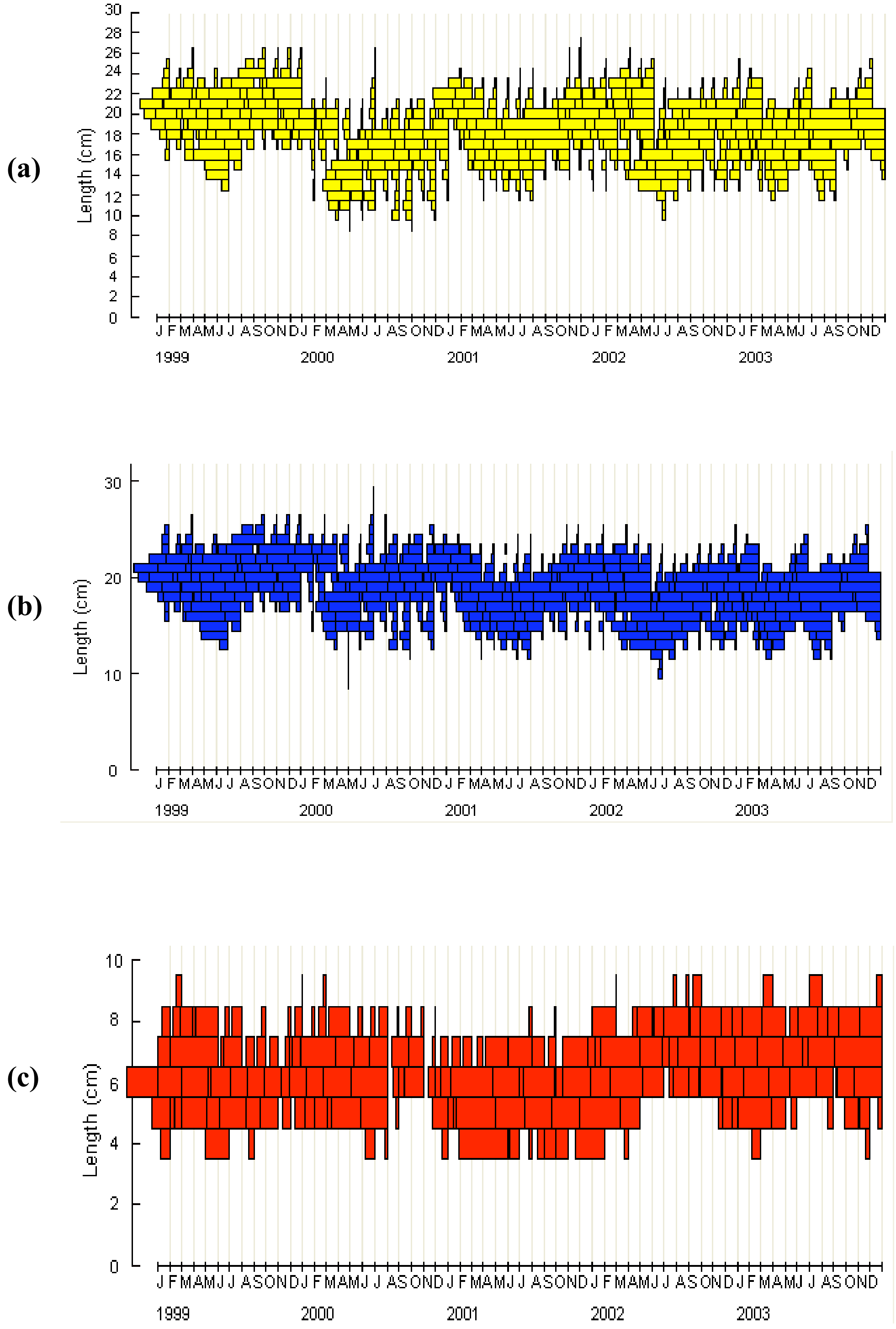


Figure 3. Monthly length-frequency histograms of the commercial catch of (a) moonfish, (b) short mackerel, and (c) tropical anchovy for 1998-2003 in the Lingayen Gulf, Philippines.

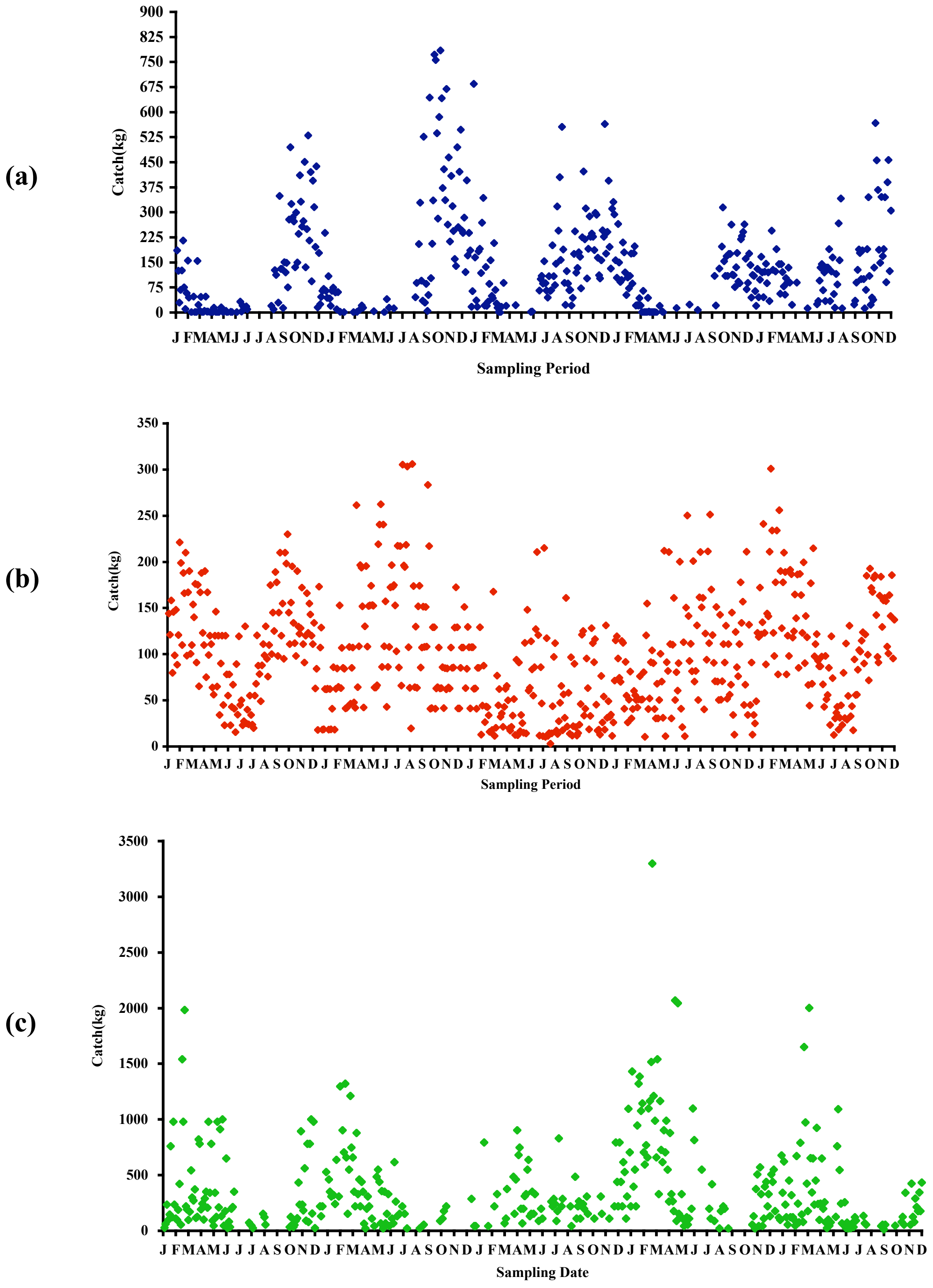


Figure 4. Commercial catch data collected every other two days for (a) moonfish, (b) short mackerel, and (c) tropical anchovy harvested from 1999-2003 in the Lingayen Gulf, Philippines.

Table 1. Annual catch and effort data for the commercial and the municipal fisheries for 1976 to 2004 in the Lingayen Gulf, Philippines.

Time	Commercial Fisheries		Municipal Fisheries	
	Catch (kgs)	Effort (hours)	Catch (kgs)	Effort (hours)
1976	1449	4937	16432	9090000
1977	2060	7269	17487	9787500
1978	2033	6912	19518	10329750
1979	2119	7258	20678	10651500
1980	3051	7410	19033	12076800
1981	7692	7692	18757	12456000
1982	7915	7546	19676	12742800
1983	7123	7591	24158	14117772
1984	7113	8069	20910	14582552
1985	9105	10248	23914	13568566
1986	9118	10760	31996	13182423
1987	8905	9985	22035	15148816
1988	7965	10364	30298	13522985
1989	7358	9856	20027	13694910
1990	7411	9915	26125	14176641
1991	8002	10540	25304	13296416
1992	4641	11562	30914	15903172
1993	4966	10291	23727	16035546
1994	3427	9343	24006	16774515
1995	5380	10032	25195	16842458
1996	3389	10884	21382	16842458
1997	2034	11108	20231	17856698
1998	1963	10518	22461	17981378
1999	1863	11387	22482	18347018
2000	2250	12077	22844	18362854
2001	2525	9552	21583	19101651
2002	3470	10699	25338	19708647
2003	4137	12082	27498	19186149
2004	3984	12137	27770	19695457

Time series of annual catch and effort data (Table 1) of municipal and commercial fisheries from 1976 to 2004 were provided by BFAR and the Bureau of Agricultural Statistics (BAS). Annual catch and effort data for the commercial and municipal fisheries were analyzed separately by surplus production modeling.

Values of life history information (Table 2) for the three species were from reported values in the literature (Myers et al. 1995; Rose et al. 2001; Rose 2005; Froese and Pauly 2006). When species-specific information was not available, life history data of the species that belonged to the same genus or family (e.g., bay anchovy for tropical anchovy) were used. These basic life history parameters were used in various aspects of the stock assessment analyses.

Table 2. Life-history parameters of the moonfish, short mackerel and tropical anchovy harvested in the Lingayen Gulf, Philippines (L_{max}=maximum length (cm); L_m=length at maturity (cm); L_c=length at first capture (cm); Aws=average weight of a spawner (grams); Awe=average number of eggs produced per gram of body weight; Awf=average number of eggs produced per female; Nb=number of spawning batches per year; Ss=months of the spawning season).

Species	L_{max}	L_m	L_c	Aws	Awe	Awf	Nb	Ss
Moonfish	30.00	14.00	9.00	84.50	385.00	32532.00	7.00-10.00	March-August
Short mackerel	34.50	17.00	16.00	326.00	319.00	103994.00	6.00-8.80	March -September
Tropical Anchovy	15.80	10.20	8.10	32.44	517.00	16772.00	12.00-30.00	February-June

2. METHODS

2.1. Overview of the Methods

The overall logic of my analysis is shown in Figure 5. The monthly length frequencies of commercial catch were first analyzed to identify cohorts and then the parameters of the von Bertalanffy growth model were estimated using the lengths associated with these cohorts. I then estimated natural mortality rates using two alternative equations (Pauly 1980; Beddington and Kirkwood 2005) based on the estimated von Bertalanffy parameters and values of other life-history traits. Total mortality rates (Z) were estimated using the declining numbers of individuals associated with these cohorts as they age (i.e., length-converted catch curves). Current fishing mortality rates ($F_{current}$) were then estimated by the difference between total mortality and natural morality rates. The von Bertalanffy growth parameters and total and fishing mortality rates were determined for each of the five years for each species. The two alternative estimates of natural mortality resulted in two estimates of $F_{current}$ for each year.

Estimates of fishing mortality at maximum sustainable yield (F_{msy}) were determined from the life-history invariants approach, further analysis of the monthly catch data involving yield-per-recruit analysis, and by application of the individual-based population model. Life-history invariants resulted in two estimates of F_{msy} for each species for each year based on whether I used the density-dependent or density-independent versions of the life-history invariants approach. The yield-per-recruit analysis of the catch curve also resulted in two estimates of F_{msy} each year, depending on which estimate of natural mortality was used. The individual-based modeling approach was not year-specific but generated a range of F_{msy} values for each species depending on alternative assumptions about recruitment steepness, degree of interannual variability, and presumed age at first spawning.

The fourth and final approach, surplus production modeling, was applied to total catch and effort separately for commercial and municipal fisheries. Two estimates of annual F values were predicted for the commercial and municipal fisheries using a least-squares fitting method (Kirkwood and Aukland 2001) and a Bayesian fitting method (Hilborn 1994).

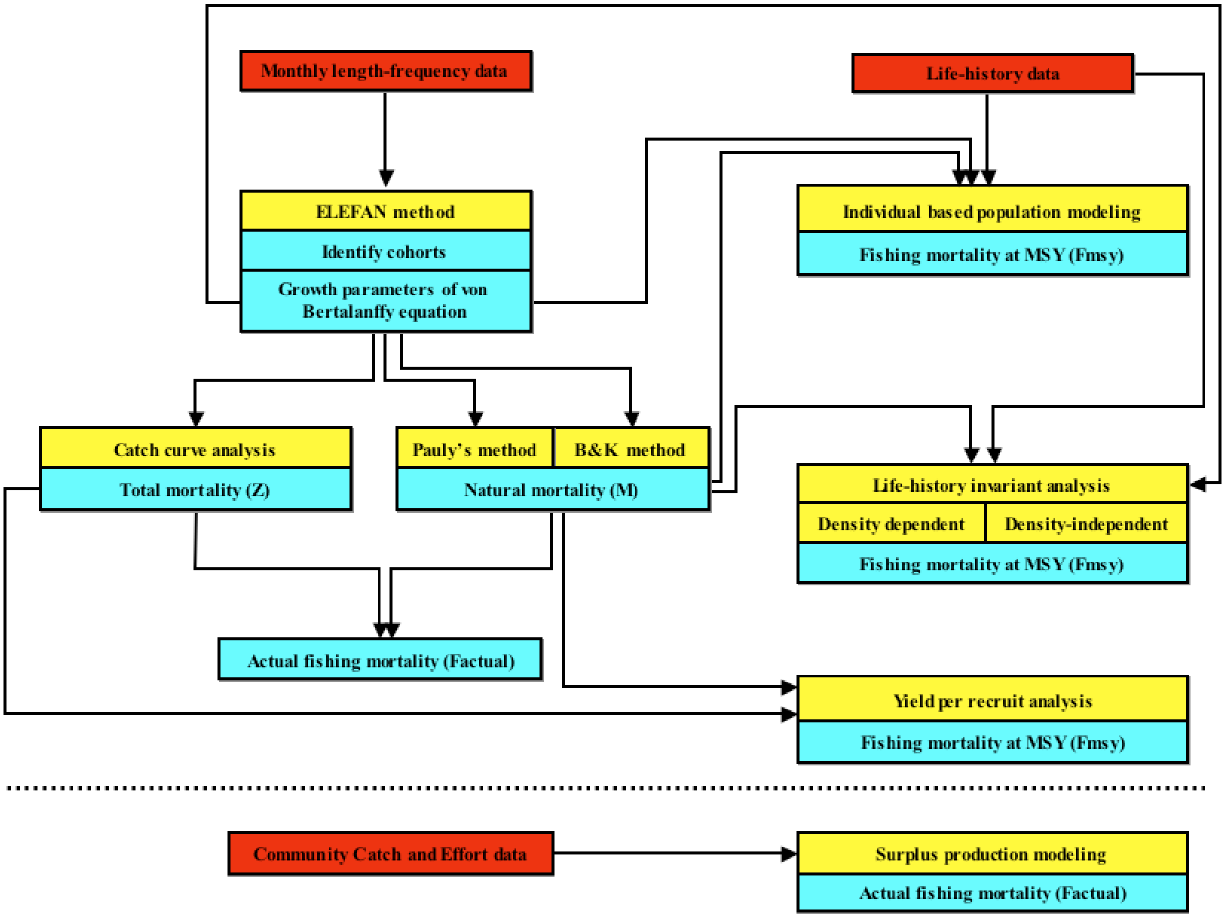


Figure 5. Flow diagram showing the overall flow of information for computing current fishing mortality rates ($F_{current}$) and fishing mortality rate at maximum sustainable yield (F_{msy}). (B&K= Beddington and Kirkwood method (2005) used to estimate natural mortality rate).

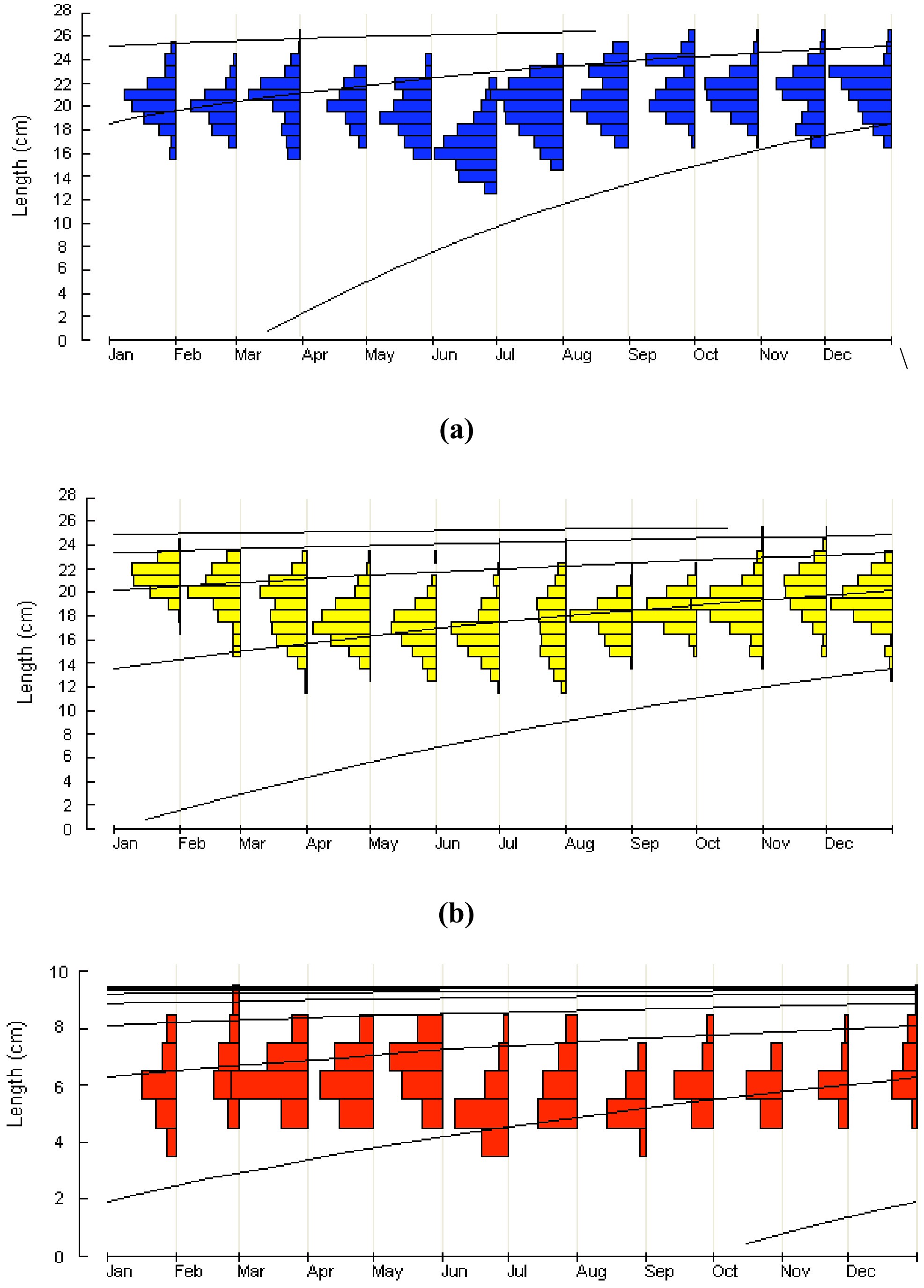
2.2. Identification of Cohorts and Estimation of Growth Parameters

Parameters of the von Bertalanffy growth model (Figure 5) were estimated for each year by applying the ELEFAN (Electronic Length Frequency Analysis) program incorporated in the FiSAT software (Fish Stock Assessment Tool, Gayanillo and Pauly 1997; Gayanillo et al. 2002) to the monthly length-frequencies of each of the three species. The von Bertalanffy growth model (Gayanillo and Pauly 1997; Pilling et al. 2002; Froese and Binohlan 2003; Beddington and Kirkwood 2005) was of the form:

$$\mathbf{L_t = L_\infty\,[1\text{-}e^{-K\,(t\text{-}t_o)}]} \qquad \mathbf{(1)}$$

where L_t is the predicted length of fish (cm) at age t, L_∞ is the asymptotic length (cm), K is the rate ($year^{-1}$) at which L_∞ is reached (referred to as growth rate), and t_o is the "age of the fish at zero length".

The ELEFAN program identifies cohorts from length-frequency data and then estimates the parameters of the von Bertalanffy growth model using the lengths associated with each cohort as they age. ELEFAN combines the method of Petersen (1892) with a modal progression analysis (Gayanillo and Pauly 1997; Gayanillo et al. 2002). ELEFAN searches for a growth rate that will fit the lengths associated with the peaks of the length-frequency data such that an optimum fit is achieved (see Figure 6 for an example). The computation in ELEFAN is similar to how linear regression is fitted to data. ELEFAN assumes that length-frequency samples are representative of the population, and that all differences in length can be attributed to differences in age and interannual variation in growth rate.



(a)

(b)

(c)

Figure 6. Example of the best fit of the von Bertalanffy growth curves estimated using ELEFAN method overlaid on to the original length frequency histograms for (a) moonfish (L_∞=27.30cm; K=1.40 year^{-1}), (b) short mackerel (L_∞=26.25cm; K=0.73 year^{-1}), and (c) tropical anchovy (L_∞=9.45cm; K=0.86 year^{-1}).

2.3. Estimation of Natural Mortality Rates (M)

The instantaneous rate of natural mortality (M) is defined as the death of fish from any cause except fishing (e.g., ageing, predation, cannibalism, disease). Natural mortality rates were determined using two commonly used empirical relationships; both utilize estimated values of the von Bertalanffy growth model (Figure 5). Pauly (1980) derived a relationship between M and the parameters of the von Bertalanffy growth model and the mean annual water temperature based on 175 fish populations:

$$\mathbf{M = 10\wedge(-0.0066 - 0.279*Log(L_{\infty}) + 0.6543*Log(K) + 0.4634*Log(T))} \qquad \mathbf{(2)}$$

For this study, I used a mean annual temperature of 28.5 ^{o}C for all five years, which is typical of temperatures in the Lingayen Gulf.

Beddington and Kirkwood (2005) also proposed a generic relationship between natural mortality rate and the parameter K of the von Bertalanffy growth model:

$$\mathbf{M = 1.5*K} \qquad \mathbf{(3)}$$

Both empirical relationships were used to estimate the natural mortality rates of the three species in each of the five years.

2.4. Estimation of Current Fishing Mortality Rates ($F_{current}$)

Current fishing mortality rates ($F_{current}$) were estimated as the difference between total mortality rates (Z) estimated from the catch data and the estimated natural mortality rates (M) (Figure 5). Total mortality was determined using the FiSAT program that converts the length-frequencies into a catch curve (Pauly 1984; Gayanillo and Pauly 1997; Gayanillo et al. 2002).

Length-converted catch curves are functionally equivalent to age-structured catch curves (Gulland and Rosenberg 1992; Spare and Venema 1998), but are commonly used when age data are difficult to obtain (Gulland and Rosenberg 1992; Gayanillo and Pauly 1997). The method is based solely on length-frequency samples and assumes that the sample sizes are large enough and covers enough age groups to effectively represent the average population structure over a specified period of time (Gayanillo and Pauly 1997; Spare and Venema 1998).

The estimation of total mortality from a length converted catch curve involves a series of steps. First, monthly catch data were pooled to obtain a single, large sample representative of the population for a given period. I pooled the monthly length-frequencies for each year. Second, a catch curve was constructed using large sample and a set of growth parameter. Finally, Z is estimated from the slope b, with sign change, of the descending right arm of the catch curve using linear regression (see Figure 7 for an example).

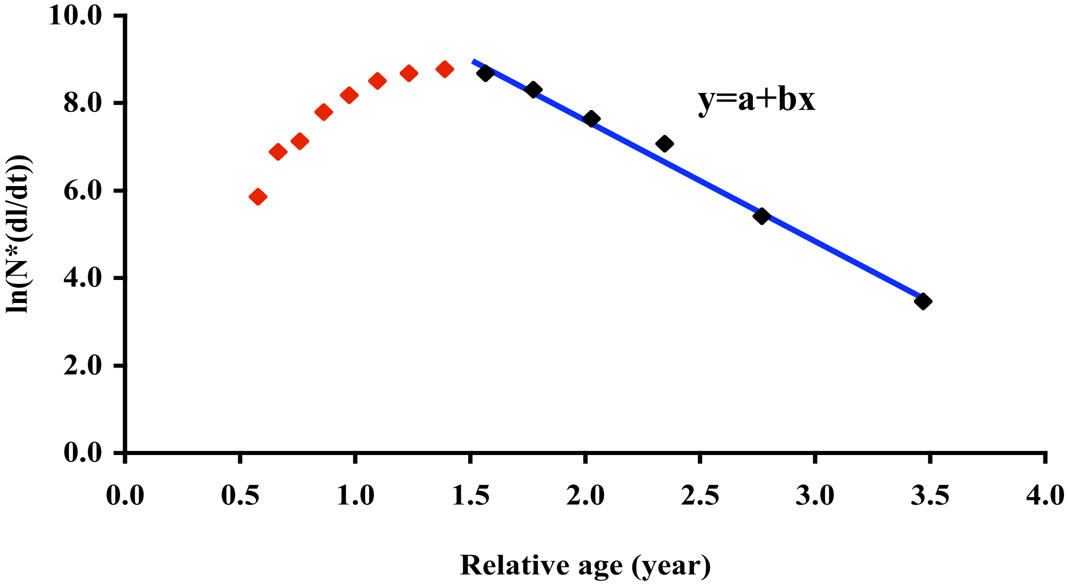


Figure 7. Example of how total mortality (Z) is estimated as the slope of the descending limb of the length-converted catch curve. This example is for moonfish caught in the commercial fisheries of the Lingayen Gulf, Philippines, and resulted in an estimate of Z of 4.53 year^{-1}.

Current fishing mortality rates ($F_{current}$) were estimated for each year and species as the difference between the catch-curve derived total mortality rate and the estimated natural mortality rate.

2.5. Estimation of Fishing Mortality at MSY (F_{msy})

2.5.1. Estimation of F_{msy} using Life-history Invariants

General relationships have been suggested that relate stock biomass at MSY (B_{msy}) and F_{msy} (or equivalent to exploitation rate at MSY) to basic life-history traits. Beddington and Kirkwood (2005) recently synthesized this approach for use with data-poor fisheries. Life-history invariants are empirical relationships that relate growth, mortality, and reproduction traits to each other so that if one is known the other can be estimated.

Beddington and Kirkwood (2005) used several life-history invariants to derive a relationship between exploitation rate at MSY and the parameters of the von Bertalanffy growth model and natural mortality rate estimated using Pauly's equation (Equation 2). They presented two versions of this relationship to estimate F_{msy}. The first version corresponds to a density-independent situation and assumes constant recruitment. F_{msy} ($year^{-1}$) increases with increasing K and increasing length at first capture (L_c).

$$\mathbf{Fmsy=(0.6*K)/(0.67*L_c)} \qquad \mathbf{(4)}$$

The second version takes into account density-dependence and assumes that recruitment varies with spawning stock biomass (SSB) according to a Beverton-Holt stock-recruitment relationship. Beddington and Kirkwood (2005) reported an equation that closely approximated the relationship between F_{msy} and L_c, K of the von Bertalanffy growth model and the assumed steepness value (h) of the spawner-recruit relationship.

Fmsy=a(L_c,h)K **(5)**

where a(L_c,h) is function of L_c and h that is shown in Figure 3 of Beddington and Kirkwood (2005). The parameter L_c is defined as the length of a fish stock at which first becomes vulnerable to fishing and, as used by Beddington and Kirkwood, is reported as relative to L_∞ of the von Bertalanffy growth model. In practice, h is a parameter that is difficult to estimate and that requires substantial time series of stock and recruitment data corresponding to a wide range of spawning stock biomass (Gallucci et al. 1997; Myers et al. 1999; Quinn and Deriso 1999; Haddon 2001).

Most of the estimates of h are predominantly for temperate species. For fisheries in developing countries, it is difficult to obtain reliable direct estimates of h (Haddon 2001), though it maybe possible to infer ranges from published estimates from similar species. Myers et al. (1999) summarized estimates of h for a variety of species using a comprehensive collection of stock recruitment data. Beddington and Kirkwood (2005) combined this information with the estimates of growth parameters obtained from Froese and Pauly (2004) in their derivation of equation (5). I used general values of L_c=0.6 and h=0.7, which resulted in a value of a(L_c,h) equal to 0.4 from Figure 3 of Beddington and Kirkwood (2005).

I used equations (4) and (5), with year-specific estimates of the K and L_∞, to obtain two estimates of F_{msy} for each species on an annual basis.

2.5.2. Estimation of F_{msy} from Length-based Catch Analysis

Beverton and Holt (1966) suggested that F_{msy} could be predicted from life-history information (e.g., growth and mortality) using the relative yield-per-recruit (Y'/R) approach. The yield-per-recruit approach describes the state of the stock and expected yield in a situation where a given fishing pattern had been operating for a long time (Gayanillo and Pauly 1997).

The model is implemented as a function of L_c, L_∞, K, and M to derive crude estimates of F_{msy}. I used the yield-per-recruit program in FiSAT, which reports fishing mortality rate at MSY in terms of exploitation rate rather than as an instantaneous rate. The exploitation rate (E_{msy}) was converted to instantaneous rates (F_{msy}) through the relationship:

$$\mathbf{F_{msy}=M*E_{msy}/(1-E_{msy})} \qquad \mathbf{(6)}$$

An example of a yield-per-recruit curve for moonfish is shown in Figure 8.

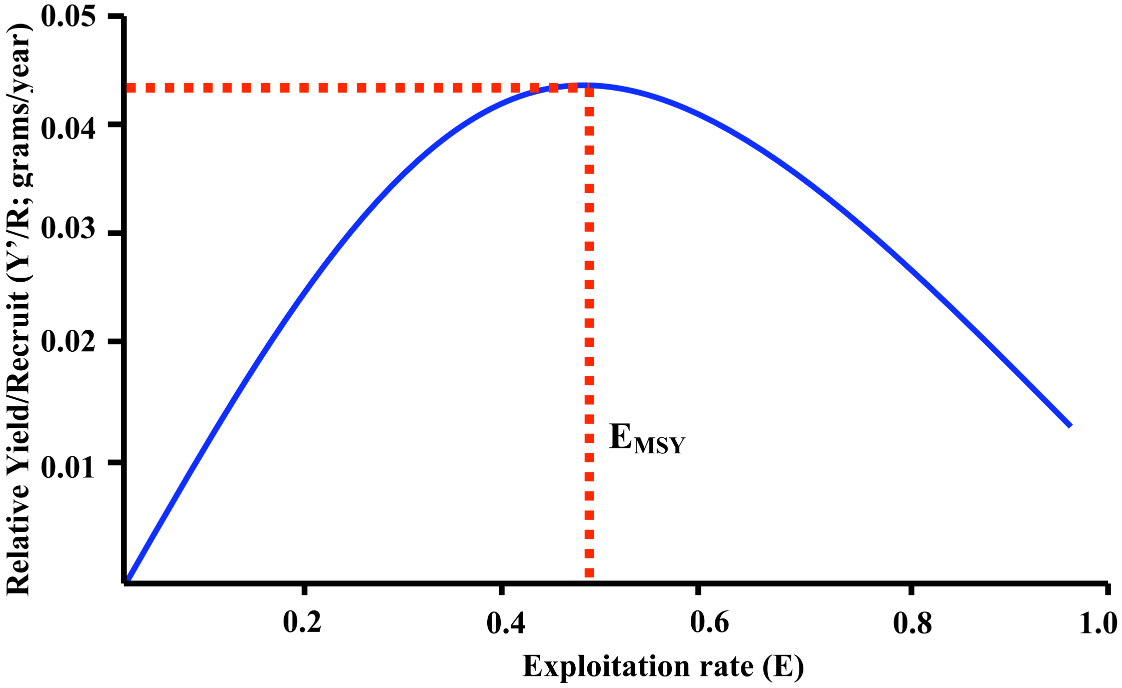


Figure 8. Example of a relative yield-per-recruit curve of moonfish caught in the commercial fisheries of the Lingayen Gulf, Philippines showing exploitation at maximum sustainable yield (E_{msy}).

2.5.3. Estimation of F_{msy} from Individual-based Population Model

The individual-based population model followed individual fish through daily growth, mortality, and recruitment for 200 years. On any day, the sum over individuals resulted in the population-level predictions. The model used a 360-day year, from January through December. While the model is not purely species-specific, three sets of parameter values were used to represent some of the life-history differences in moonfish, short mackerel, and tropical anchovy (Table 3; Figure 5). However, several key parameters related to the spawner-recruit relationship were estimated from other species and the same values were used for all three species. Length in the model was in centimeters and weight was grams wet weight.

The model begins with a fixed number of individuals that were generated from a specified age-distribution. The first day of spawning and the duration of spawning in days were specified for each species. On the first day of spawning each year, the spawning biomass was computed as the sum over individual weights. Two alternative assumptions were simulated: all individuals born during the previous year were included, or only individuals at least ten months of age at the beginning of the spawning season were included. Under both assumptions, individuals had to wait until they lived through a January before they were included in the spawning biomass. The first alternative assumes that even individuals spawned at the end of the spawning season would mature in time during the next year's spawning seasons to contribute. They are included in the computation of spawning biomass because the model computes spawning biomass once per year at the beginning of the spawning season. The second assumption is the other

Table 3. Life-history parameters used in individual-based population model (IBM) to estimate fishing mortality at maximum sustainable yield (F_{msy}) of the Moonfish, Short mackerel, and Tropical anchovy commercial fisheries in the Lingayen, Gulf, Philippines.

Parameter	Units	Species		
		Moon	Mackerel	Anchovy
1. Length at infinity (L_∞)	cm	27.1	27.3	9.5
2. Growth rate (K)	year^{-1}	1.2	1.2	1.2
3. Length at first capture (Lc) (i.e., 6 months of age)	cm	7.6	10.4	4.0
4. T-zero (t_o)	months	2.7	1.2	0.53
5. Natural mortality (M)	year^{-1}	1.9	1.9	1.3
6. Steepness (h)	fraction	Either 0.7 or 0.8		
7. Annual multiplier of recruitment	fraction	Either a multiplier of one every year or a random deviate from a lognormal distribution with mean = 0.41 and SD = 0.9		
8. Spawning stock biomass (SSB) (with h=0.8)	grams	5000	5000	5000
9. Maximum recruitment (R_{max}) (calibrated to h=0.8)	number of individuals	125	125	1850
10. a of L=aW**b		0.0153	0.0061	0.0364
11. b of L=aW**b		3.00	3.21	2.74
12. Age at first maturity (t_m)	months	Either all individuals are assumed mature for the next spawning season or only those at least 10 months old at beginning of next spawning season		
13. Spawning season	calendar days	78 to 227	78 to 258	46 to 166

extreme that only individuals were mature at the beginning of the spawning season would contribute to that year's spawning.

Spawning biomass was then used with a Beverton-Holt spawner-recruit relationship to determine the total number of recruits for that year. Recruits are defined as the number surviving to 6 months of age. The steepness parameter was set to 0.7 and to 0.8. The value of 0.7 is common among many fish species (Rose et al. 2001), and the value of 0.8 was estimated from 32 years (1964 to 1995) of spawner-recruit data for northern anchovy (Rose 2005). The other parameter of the spawner-recruit relationship, maximum recruitment, was determined by calibration, as described below. As part of the fitting of the spawner-recruit relationship, the mean and standard deviation of log-transformed recruitment residuals was also computed and used to impose a random multiplier to annual recruitment in the model. A deviate from a lognormal distribution with estimated mean and standard deviation was generated each year and multiplied by the recruitment predicted by the spawner-recruit relationship.

New individuals were introduced to the population using a function that introduced zero individuals on the first day of spawning, linearly increased to a maximum on the day at the midpoint of the spawning season, and linearly decreased to zero on the final day of spawning. The area under this triangular function was adjusted to one to ensure that the sum of the individuals added daily for the year equaled the total annual number of recruits for the year. Each individual that was added according to the spawning season then had no mortality (i.e., the spawner-recruit relationship already included mortality of pre-recruits) and was not allowed to grow in weight. Individuals were aged daily and upon reaching 6 months of age were considered vulnerable to the specified natural mortality rate and the specified fishing mortality rate. Daily yield in biomass (number times weight) was accumulated from January through December and was reported as annual yield. When an individual had lived 5 years, it was removed from the population on January 1 of the next year.

Growth was modeled as daily increase in length based upon a von Bertalanffy curve. Newly introduced individuals at 6 months of age were assigned the length at first capture, which corresponded to a 6-month-old individual and then its length followed the length trajectory through age (time) dictated by the growth curve. Each day, a length-weight relationship was used to convert length into weight.

While the steepness parameter could be specified, the virgin spawning biomass and maximum recruitment values were unknown. The virgin spawning biomass was arbitrarily set to 5,000 g. For each species version of the model, the model was run for 200 years with the known steepness and maximum recruitment was varied until the long-term spawning biomass equaled about 5,000 g. This ensured that each population would be their virgin spawning biomass under no-fishing conditions (i.e., not too high in terms of biomass on the spawner-recruit curve).

For numerical purposes, 400 model individuals were simulated for each of the 5 age classes. Each model individual was assigned an initial worth equal to how many populations recruit it represented. Mortality was simulated by decrementing the worth of the individual to reflect natural and fishing mortality.

Parameter values (Table 3) for natural mortality and the von Bertalanffy curve were obtained from the catch-curve and other analyses. I averaged the M, L_∞, K, and length at first capture for the 5 years for each of the species. Steepness was specified as 0.7 or 0.8, and with virgin spawning biomass set to 5,000 g, maximum recruitment was determined by calibration. For calibration of maximum recruitment, steepness was set to 0.8, the multiplier of recruitment was set to one, and all individuals born on one year were assumed to spawn the following year. Different values of maximum recruitment were then tried until the long-term predicted spawning biomass was very close to the desired 5,000 g for each species. The calibrated maximum recruitment values were 125 individuals for moonfish, 125 individuals for short mackerel, and 1,850 individuals for tropical anchovy. The conditions assumed for calibration were those that would lead to the highest yields. Using the maximum recruitment values determined under these best conditions for the other conditions (steepness of 0.7, lognormal variability, and assuming only those individuals at least 10 months old on the first day of spawning spawned) would generate results that erred on the side of being protective of the resource.

For each species, 200-year runs were performed for eight combinations of conditions. The eight combinations were the alternative assumptions about maturity (all YOY or only mature YOY), a steepness value of 0.7 or 0.8, and without and with annual lognormal multipliers on recruitment. For each condition, 200-year simulations were performed for a range of fishing mortality rates between zero and 4.0 year^{-1}. Annual yield was averaged over years 11 to 200 and plotted against the associated fishing mortality rate. F_{msy} was determined by fitting a nonlinear regression model (Weibull function, SPSS 1996) to average annual yield and fishing mortality rate, and the value of Fmsy was determined as the x-axis value (fishing mortality rate) associated with the maximum y-value (yield). R-square (r^2) values ranged from 0.67 to 0.93.

2.5.4. Estimation of Community F_{msy} and $F_{current}$ from Surplus Production Model

Surplus production models are the simplest analytical method (Hilborn and Walters 1992; Hilborn 1994; Haddon 2001) that can be used to characterize the status and productivity of fish populations (Haddon 2001). Surplus production models are relatively simple to apply because they pool the overall effects of recruitment, growth, and mortality into a single production function (Hilborn 1994; Punt and Hilborn 2001; Jacobson et al. 2002). The stock is considered solely as undifferentiated biomass. The model ignores differences in age, size, and sex, and assumes that the rates of immigration and emigration are negligible (Hilborn 1994).

F_{msy} and F_{opt} were estimated by application of the Schaefer surplus production model to catch-per-unit-effort data of the commercial and municipal fisheries (Figure 9) of Lingayen Gulf. The surplus production model assumes logistic population growth with the addition of a loss rate for harvest:

$$\mathbf{B_{t+1} = B_t + g(B_t) - C} \qquad \mathbf{(7)}$$

and

$$\mathbf{g(B_t) = (rB_t(1 - B_t)/K)} \qquad \mathbf{(8)}$$

where B_t is the stock biomass (kilograms) at time t, r is the intrinsic rate of population growth (year^{-1}), K is the carrying capacity (kilograms), and C is the catch or harvest rate (kilograms-year^{-1}). Catch rate is assumed to be proportional to stock biomass and fishing mortality rate, with fishing proportional to effort:

$$\mathbf{C = F^*B} \qquad \mathbf{(9)}$$

$$\mathbf{F = q^*f} \qquad \mathbf{(10)}$$

where q is the catchability coefficient.

Two alternative fitting methods (least-squares and Bayesian) included in a software package distributed by the FAO (Hilborn 1994; Punt and Hilborn 2001) were used to apply the surplus production model to annual catch and effort data of the municipal and the commercial fisheries of Lingayen Gulf (Figure 9). Annual catch and effort data, not differentiated by species, from 1976 to 2004 were available for both fisheries. The model was applied to each fishery separately because they fish different areas in the Gulf and there was not an obvious way to standardize the effort between the two fisheries to combine the data into a single catch-per-unit-effort time series. In these situations, either both fisheries are included in a single model simultaneously or the model is applied to each fishery separately (Hilborn 1992; Kirkwood et al. 2001). A variety of stock status benchmarks, including F_{msy}, was derived from the fitted r and K values of the surplus production model. Maximum sustainable yield (MSY) was computed as kr/4, F_{msy} as r/2, and F_{opt} as 0.63*F_{msy}. The application of the surplus production model also provided another estimate of $F_{current}$ that was obtained by the product of q times the effort (f) in each year.

All results of the surplus production modeling relate to the harvested fish community because species were not identified in the catch. The application of surplus production modeling makes use of the long historical data record of total catch and effort to infer any trends in general fishing mortality rates.

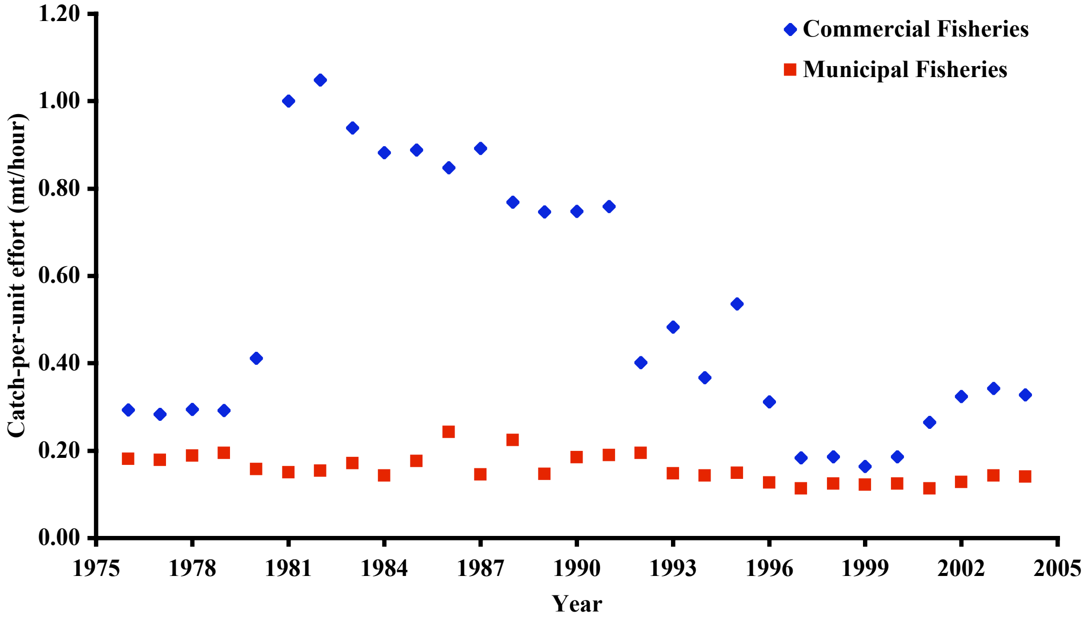


Figure 9. Annual catch-per-unit effort (CPUE) values of the commercial and municipal fisheries of Lingayen Gulf from 1976-2004.

3. RESULTS

3.1. Life-history and Growth Parameters

Length at first capture (L_c) computed directly from the length-frequency catch data was relatively consistent among years for each of the three species (Table 4). Length at first capture varied from 6.0-8.0 cm for moonfish, from 8.0-13.0 cm for short mackerel, and was 4.0 cm for all years for tropical anchovy. Length at first capture did not show any obvious temporal trends for any of the species (Figure 10a).

Estimated length infinity (L_∞) values of the fitted Von Bertalanffy curve were longer for moonfish and short mackerel compared to tropical anchovy, and showed little variation among years (Table 4, Figure 10b). Length infinity was estimated to be 26.25-28.35 cm for moonfish, 26.25-30.45 cm for short mackerel, and 8.4-9.45 cm for tropical anchovy.

Growth rates (K) of the fitted von Bertalanffy curve were highly variable among years, with low values consistently estimated for 2001 (Table 4; Figure 10c). K values varied between 0.5-1.7 per year for moonfish, between 0.75-1.7 per year for short

Table 4. Predicted length at first capture (L_c), length infinity (L_∞), and growth rate (K) for 1999-2003 for moonfish (Mn), short mackerel (Rb), and tropical anchovy (Sc) caught in the commercial fisheries of the Lingayen Gulf, Philippines.

Year	Length at first Capture (Lc; cm)			Length Infinity (L_∞; cm)			Growth Rate (K; year^{-1})		
	Mm	Rb	Sc	Mm	Rb	Sc	Mm	Rb	Sc
1999	8.00	8.00	4.00	27.30	27.30	9.45	1.40	1.40	0.86
2000	6.00	13.00	4.00	26.25	30.45	9.45	0.72	0.75	1.60
2001	8.00	9.00	4.00	28.35	26.25	8.40	0.50	0.73	0.93
2002	8.00	12.00	4.00	27.30	26.25	9.45	1.70	1.40	1.70
2003	8.00	10.00	4.00	26.25	26.25	9.45	1.70	1.70	1.10

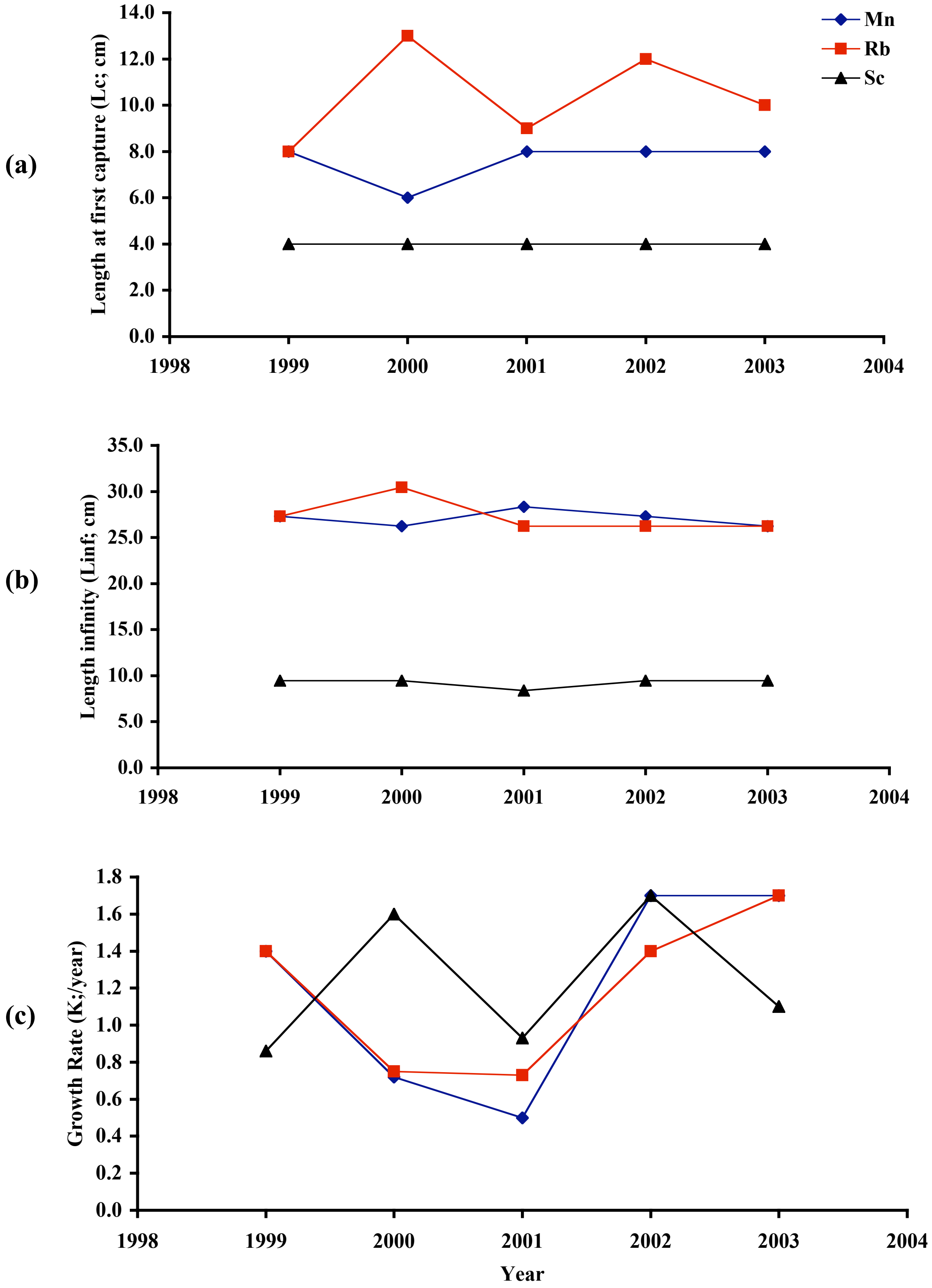


Figure 10. Annual estimates for 1999-2003 of (a) length at first capture (Lc), (b) length infinity (L_∞) and (c) growth rate (K) for moonfish (Mn), short mackerel (Rb), and tropical anchovy (Sc) caught in the commercial fisheries of the Lingayen Gulf, Philippines.

mackerel, and between 0.86-1.7 per year for tropical anchovy. Estimated growth rates were lowest or second to lowest in 2001 for all three species (Figure10c).

3.2. Estimated Natural Mortality Rates (M)

Estimated natural mortality rates (M), while highly variable among years, were on average similar for the three species and were generally lower for the Beddington and Kirkwood method compared to the Pauly method (Table 5). For example, for the Pauly method, estimated natural mortality rates varied from 1.16-2.65 per year for moonfish, from 1.49-2.65 per year for short mackerel, and from 2.25-3.52 per year for tropical anchovy. Yet, the averaged mortality rates were fairly similar: 2.05 per year for moonfish, 2.06 per year for short mackerel, and 2.85 per year for tropical anchovy. Similar interannual variability was estimated using the Beddington and Kirkwood method, with all three species having lower averaged rates (1.81 per year for moonfish, 1.80 for short mackerel, and 1.86 for tropical anchovy) than for the Pauly method. As with growth rates, natural mortality rates were generally low for 2001 for all three species.

3.3. Estimated Current Fishing Mortality Rates ($F_{current}$)

Estimated total mortality rates (Z) also varied greatly among years and were higher for moonfish and short mackerel than for tropical anchovy (Table 5). Total mortality rate averaged 4.92 per year (range: 2.58-6.54) for moonfish and 4.57 per year (range: 3.03-6.21) for short mackerel, and averaged about 60% lower (2.95 per year) for tropical anchovy. Low total mortality rates were estimated for 2001 for all three species. Current fishing mortality rates ($F_{current}$), determined as total minus natural mortality rates,

Table 5. Predicted natural mortality rate (M) and total mortality rate (Z) for 1999-2003 and averaged over years for moonfish (Mn), short mackerel (Rb), and tropical anchovy (Sc) caught in commercial fisheries of the Lingayen Gulf, Philippines. (B&K= Beddington and Kirkwood (2005) method used to estimate the rate of natural mortality).

Year	Natural Mortality (M; year^{-1})						Total Mortality (Z;year^{-1})		
	Pauly's Method			B&K Method					
	Mn	Rb	Sc	Mn	Rb	Sc	Mn	Rb	Sc
1999	2.3	2.3	2.25	2.1	2.10	1.29	4.53	4.53	2.31
2000	1.51	1.49	3.38	1.08	1.10	2.40	4.03	4.32	4.70
2001	1.16	1.52	2.45	0.75	1.13	1.40	2.58	3.03	2.07
2002	2.62	2.33	3.52	2.55	2.10	2.55	6.94	4.76	3.63
2003	2.65	2.65	2.65	2.55	2.55	1.65	6.54	6.21	2.06
Average	**2.05**	**2.06**	**2.85**	**1.81**	**1.80**	**1.86**	**4.92**	**4.57**	**2.95**

were lower for the Pauly method compared to the Beddington and Kirkwood method for natural mortality and lower for tropical anchovy than for moonfish and short mackerel (Table 6). Year-to-year estimates varied greatly due to interannual variation in the estimates of natural and total mortality rates. Looking across the two estimates of natural mortality rates (Pauly; Beddington and Kirkwood), averaged current fishing mortality rates were 2.88 and 3.12 per year for moonfish, 2.51 and 2.78 per year for short mackerel, and 0.49 and 1.109 per year for tropical anchovy. Low current fishing mortality rates were consistently estimated for 2001 for moonfish and short mackerel, but not for tropical anchovy.

3.4. Fishing Mortality at MSY (F_{msy})

3.4.1. F_{msy} from Life-history Invariants

Predicted F_{msy} values under the constant recruitment assumption (F_{msy}-cons) were higher and showed more differences among species as compared to the variable recruitment assumption (F_{msy}-var) (Table 7, Figure 13). Under the constant recruitment assumption, F_{msy} values averaged 1.90 per year (range: 0.77-2.79 or 3.6-fold) for

Table 6. Predicted current fishing mortality rates ($F_{current}$) for 1999-2003 for moonfish (Mn), short mackerel (Rb), and tropical anchovy (Sc) caught in the commercial fisheries of the Lingayen Gulf, Philippines. ($F_{current}$-p uses Pauly's equation for natural mortality rate; $F_{current}$-bk uses Beddington and Kirkwood's equation for natural mortality rate)

Year	Fishing mortality ($F_{current}$; year^{-1})					
	$F_{current}$-p			$F_{current}$-bk		
	Mn	Rb	Sc	Mn	Rb	Sc
1999	2.23	2.23	0.06	2.43	2.43	1.02
2000	2.52	2.83	1.32	2.95	3.20	2.30
2001	1.42	1.51	0.38	1.83	1.94	0.68
2002	4.32	2.43	0.11	4.39	2.66	1.08
2003	3.89	3.56	0.59	3.99	3.66	0.41
Average	**2.88**	**2.51**	**0.49**	**3.12**	**2.78**	**1.109**

moonfish, 2.58 per year (range: 1.34-3.95 or 2.9-fold) for short mackerel, and 3.13 per year (range: 2.09-4.13 or 1.9-fold) for tropical anchovy. The interannual variation was under the variable recruitment assumption (3.4-fold, 2.3-fold, and 2.0-fold) was similar to the variation under the constant recruitment assumption; however, averaged values were lower and almost identical (0.48, 0.48, and 0.49 per year) for all three species. Low values were predicted for 2001 for both the constant and variable recruitment assumptions for moonfish and short mackerel generally reflective of the low total, natural, and current fishing rates estimated for that year. Predicted F_{msy} in 2001 was never high for tropical anchovy but was also not consistently the lowest.

3.4.2. F_{msy} from Length-based Catch Analysis

Predicted F_{msy} values from the Beverton and Holt relative yield-per-recruit analysis (F_{msy}-p) were variable among years and higher for tropical anchovy compared to moonfish and short mackerel (Table 7, Figure 13). Averaged F_{msy} values for the Pauly

Table 7. Predicted fishing mortality rate at maximum sustainable yield (F_{msy}) for 1999-2003 and averaged over years for moonfish (Mn), short mackerel (Rb), and tropical anchovy (Sc) caught in the commercial fisheries in the Lingayen Gulf, Philippines. Fmsy values are shown for the life-history invariants and the length-based catch (relative yield-per-recruit) methods. (F_{msy}-cons assumes constant recruitment; F_{msy}-var assumes variable recruitment; F_{msy}-p uses Pauly's natural morality rate; F_{msy}-bk uses Beddington and Kirkwood's natural morality rate)

Year	Fishing mortality at MSY (F_{msy}; year^{-1})											
	Life-history invariants Models						Length-based catch models					
	F_{msy}-cons			F_{msy}-var			F_{msy}-p			F_{msy}-bk		
	Mn	Rb	Sc	Mn	Rb	Sc	Mn	Rb	Sc	Mn	Rb	Sc
1999	2.23	2.23	2.09	0.56	0.56	0.34	2.34	2.41	2.44	2.19	2.19	2.14
2000	0.98	1.85	3.89	0.29	0.30	0.64	1.35	1.79	3.08	0.96	1.96	3.98
2001	0.77	1.34	2.88	0.20	0.29	0.37	1.27	1.30	3.78	0.76	1.33	3.13
2002	2.71	3.95	4.13	0.68	0.56	0.68	2.74	2.82	3.17	2.65	4.23	4.23
2003	2.79	3.53	2.68	0.68	0.68	0.44	2.85	2.35	2.66	2.73	3.58	2.74
Average	**1.90**	**2.58**	**3.13**	**0.48**	**0.48**	**0.49**	**2.11**	**2.13**	**3.03**	**1.86**	**2.66**	**3.24**

and for the Beddington and Kirkwood estimates of natural mortality were 2.11 and 1.86 per year for moonfish, switched their order (2.13 and 2.66 per year) for short mackerel, and were higher (3.03 and 3.24 per year) for tropical anchovy. Interannual variability in the predicted values was also relatively large for all three species. F_{msy} values for 1999 to 2003 for Pauly and for Beddington and Kirkwood ranged between 1.27-2.85 and 0.76-2.73 for moonfish, between 1.3-2.82 and 1.33-4.23 for short mackerel, and between 2.44-3.78 and 2.14-4.23 for tropical anchovy. Predicted F_{msy} was consistently the lowest for 2001 for moonfish and short mackerel, but not necessarily so for tropical anchovy.

3.4.3.F_{msy} from Individual-based Population Model

Example annual population biomass from a single simulation of the IBM is shown in Figure 11 for moonfish. This simulation showed the variability typical of model simulations under the lognormal recruitment variability assumption. Figure 12 illustrates representative averaged annual yield versus fishing rate curves for moonfish, short mackerel, and tropical anchovy that show the data points from the IBM, the fitted regression model, and the estimated F_{msy} values. Each point on the curves is the average yield for years 120 to 200 of a 200-year simulation.

Predicted F_{msy} was higher values for tropical anchovy, the no recruitment variability assumption, for steepness of 0.8, and for the assumption that all individuals spawn the next spawning season (Table 8). Examination of each row in Table 8 showed that the highest F_{msy} was almost always associated with tropical anchovy. Using moonfish with all individuals spawning as an example, predicted F_{msy} under the no variability assumption was 1.36 per year for a steepness of 0.7 versus the higher 1.47 per year for a steepness of 0.8. Fixing the steepness value at 0.7, predicted F_{msy} for moonfish was 1.36 per year for no variability versus the lower 0.92 per year for lognormal variability assumption. Very similar patterns were predicted for short mackerel and tropical anchovy.

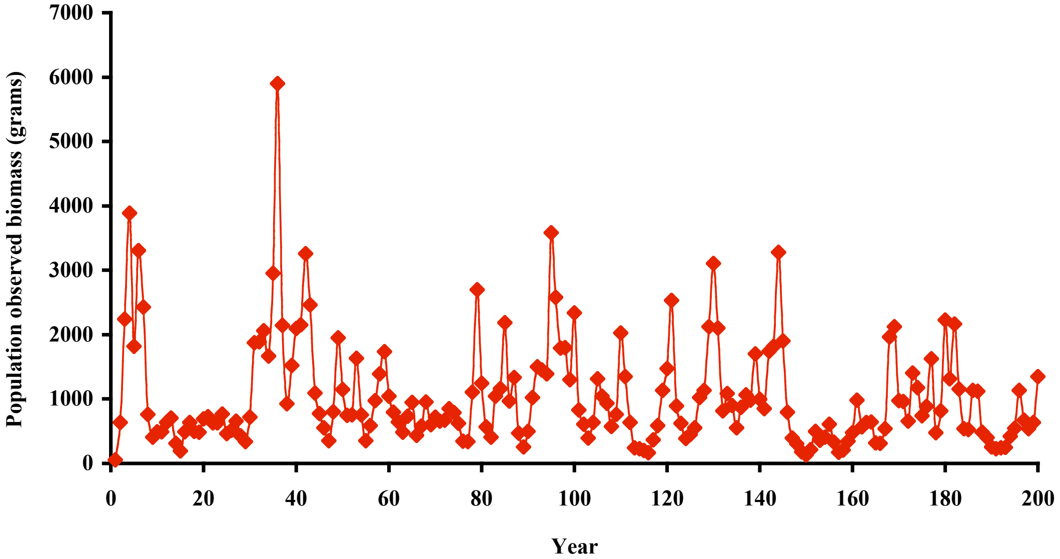


Figure 11. Simulated annual population biomass of moonfish for 200 years from a single run of the individual-based model. This simulation used a steepness of 0.7, lognormal variability of recruitment, all individuals spawning the next season, and a fishing mortality rate of 0.4 year^{-1}.

Table 8. Predicted fishing mortality at MSY (F_{msy}) derived from simulations of the individual-based population model (IBM) for moonfish (Mn), short mackerel (Rb), and tropical anchovy (Sc) in the Lingayen Gulf, Philippines.

Simulation	First maturity	Steepness	Recruitment variability	Approximate F_{msy} ($year^{-1}$)		
				Mn	Rb	Sc
1	All individuals spawn the next spawning season	0.7	None	1.36	1.40	2.30
2			Lognormal	0.92	1.06	1.74
3		0.8	None	1.47	1.77	2.32
4			Lognormal	1.44	1.73	2.24
5	Only individuals at least 10 months of age at beginning of next spawning spawn	0.7	None	1.05	0.93	1.49
6			Lognormal	0.76	0.68	1.16
7		0.8	None	1.50	1.33	2.16
8			Lognormal	0.85	0.93	1.94

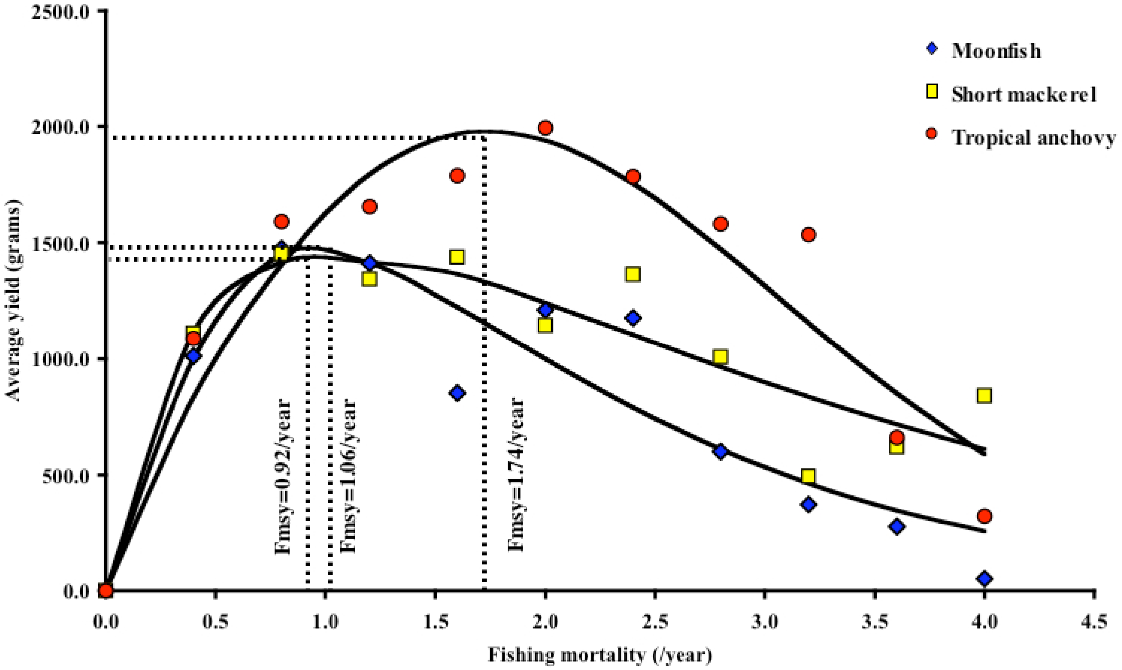


Figure 12. Illustration of the averaged yield versus fishing mortality rate results for moonfish, short mackerel, and tropical anchovy from the individual-based model. Each symbol is the averaged yield for years 20 through 200 from a simulation. The lines are the fitted regression models, and show the values of F_{msy} determined as the x-axis value associated with the maximum yield value. All simulations used a steepness (h) value of 0.7 with lognormal recruitment variability, and with the assumption that all individuals born during the previous year were included for the computation of total biomass.

3.4.4 Summary of F_{msy} and $F_{current}$ Comparison

All of the estimated F_{msy} values from the life history invariants, length-based catch analysis, and IBM simulations are summarized and compared to the estimated $F_{current}$ values in Figure 13. Almost all of the predicted $F_{current}/F_{msy}$ values are greater than 1.0 (indicating overfishing) for moonfish and short mackerel, while most values were near or less than one for tropical anchovy. The ratios that used F_{msy} values based on the life history invariant approach with constant recruitment ($F_{msy\text{-}cons}$) and the length-based catch analysis with Pauly's equation for natural mortality ($F_{msy\text{-}p}$) were consistently the lowest.

3.4.5. Community $F_{current}$ and F_{msy} from Surplus Production Model

Similar parameter estimates (Table 9) and fits to catch data (Figure 14) were obtained for the least-squares and Bayesian procedures. Estimated values of K, r, and q were almost identical between the least squares and Bayesian fits for the commercial fisheries and for the municipal fisheries. While the estimated F_{msy} values for municipal fishery were also close (0.18 per year versus 0.11 per year), the estimated F_{msy} values differed for the commercial fishery (0.59 per year for least squares and 0.89 per year for Bayesian). Fits to catch were similar for both estimation procedures (Figure 14).

The estimated parameter values for the commercial fishery were possible while the parameter estimates for the municipal fishery were highly questionable. The relatively flat likelihood functions indicated that there was high uncertainty around the parameter estimates for the commercial fishery application, and especially for the municipal fishery application (Figure 15). The values for the commercial fishery of population growth rate r (1.18 per year for least squares and 1.77 per year for Bayesian)

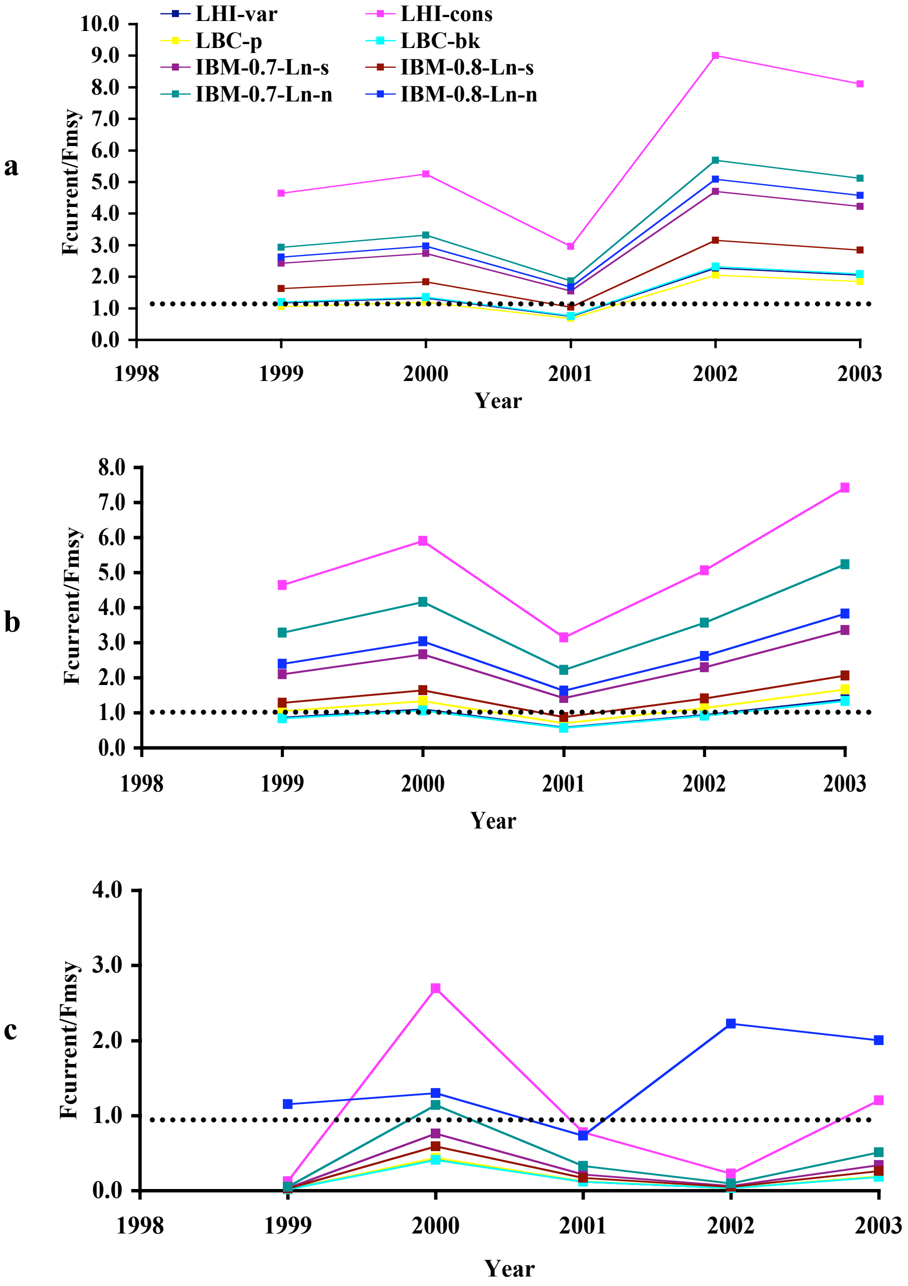


Figure 13. Annual ratio of current fishing mortality rate ($F_{current;}$ year^{-1}) to estimated fishing mortality rates at MSY (F_{msy}; year^{-1}) for (a) moonfish, (b) short mackerel, and (c) tropical anchovy caught in the commercial fisheries of the Lingayen Gulf, Philippines. (LHI-cons is life-history invariants with constant recruitment; LHI-var is life-history invariants with variable recruitment; LBC-p is length-based catch analysis with Pauly' equation; LBC-bk is length-based catch analysis with Beddington and Kirkwood's equation; all of the IBM values used lognormal recruitment variability and are coded as steepness (0.7 or 0.8) and all individuals spawn the next spawning season (s) or only individuals at least 10 months of age at the beginning of the spawning season spawn (n)).

Table 9. Predicted values of the parameters of Schaefer surplus production model from the Bayesian and least square methods applied to the total catch and effort of the commercial and the municipal fisheries of Lingayen Gulf, Philippines from 1976 to 2004 (K=carrying capacity; r=instantaneous rate of population growth; q=catchability coefficient; F_{msy}=fishing mortality at MSY).

Parameters	Unit	Least Square Method		Bayesian Method	
		Commercial Fisheries	Municipal Fisheries	Commercial Fisheries	Municipal Fisheries
K	kg	220546.70	1604862.00	213047.00	1520824.30
r	$year^{-1}$	1.18	0.37	1.77	0.35
q		3.84E-04	1.21E-07	3.55E-04	1.20E-07
F_{msy}	$year^{-1}$	0.59	0.19	0.89	0.18

and for F_{msy} (0.59 per year and 0.89 per year) were possible. The values for the municipal fishery (r=0.37 and 0.35 and F_{msy}=0.19 and 0.18 per year) were unrealistically low.

Annual fishing mortality rates ($F_{current}$) estimated from the surplus production model for the commercial and municipal fisheries generally increased between 1976 and 2004 (Figure 16). This seems reasonable given the generally declining catch-per-unit-of-effort in both fisheries (Figure 9). The unreasonable parameter estimates prevent further comparisons of the estimated fishing mortality rates to the estimated F_{msy} values at the community level. However, it is interesting to note that the estimated fishing rates ($F_{current}$) for the commercial fishery as a whole were similar to those estimated individually for moonfish and short mackerel (two dominants in the catch) from the analysis of the species-specific length-frequency catch data. Community-wide $F_{current}$ values increased from about 2.0 per year to a maximum of about 4.0 per year (Figure 16a). $F_{current}$ values for moonfish and short mackerel ranged from 1.42 per year to 4.39 per year (Table 6).

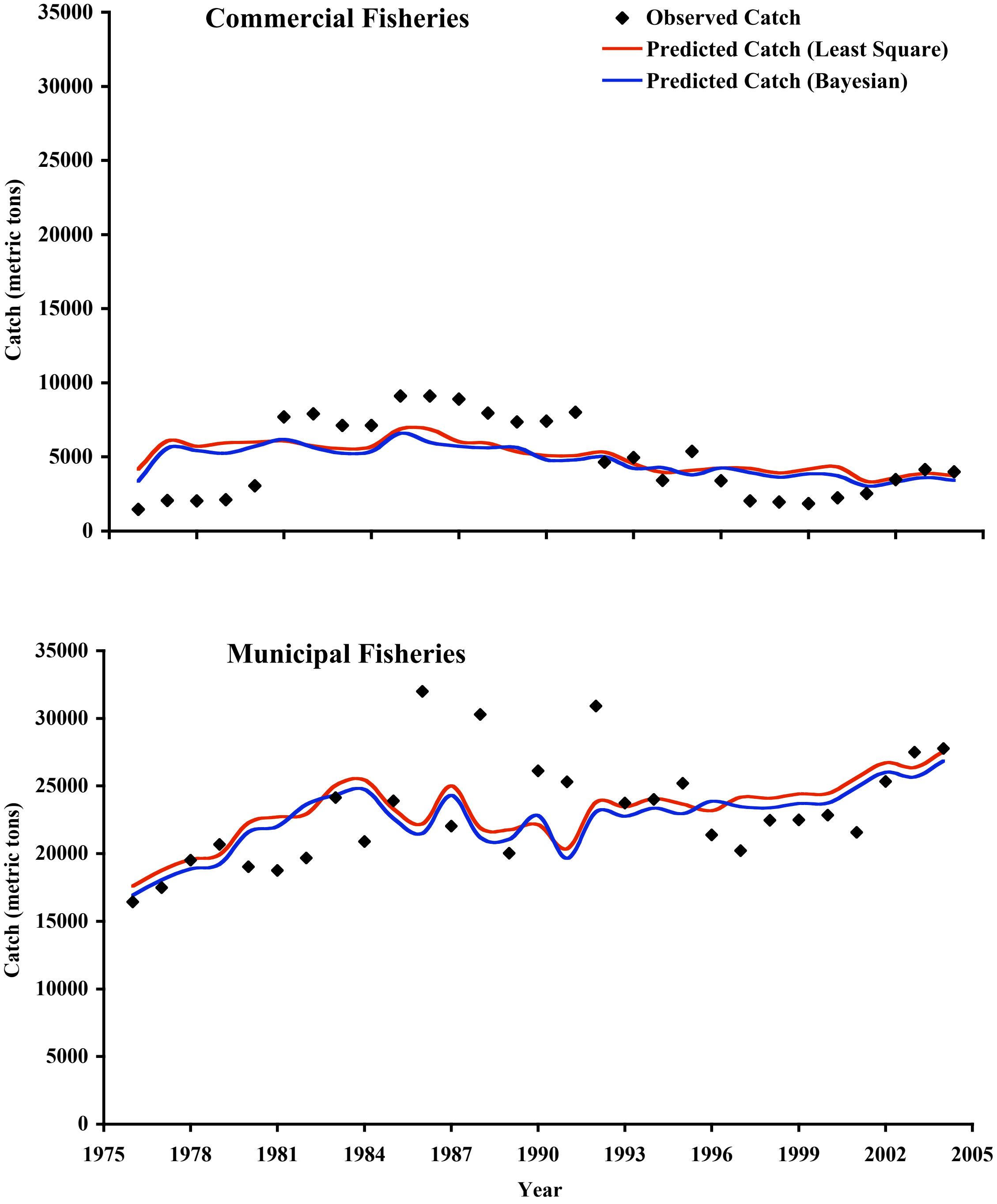


Figure 14. Predicted and observed annual catches of commercial and municipal fisheries of the Lingayen Gulf from 1976-2004. Predicted catches are shown for the least squares and Bayesian fits of the model.

Commercial Fisheries **Municipal Fisheries**

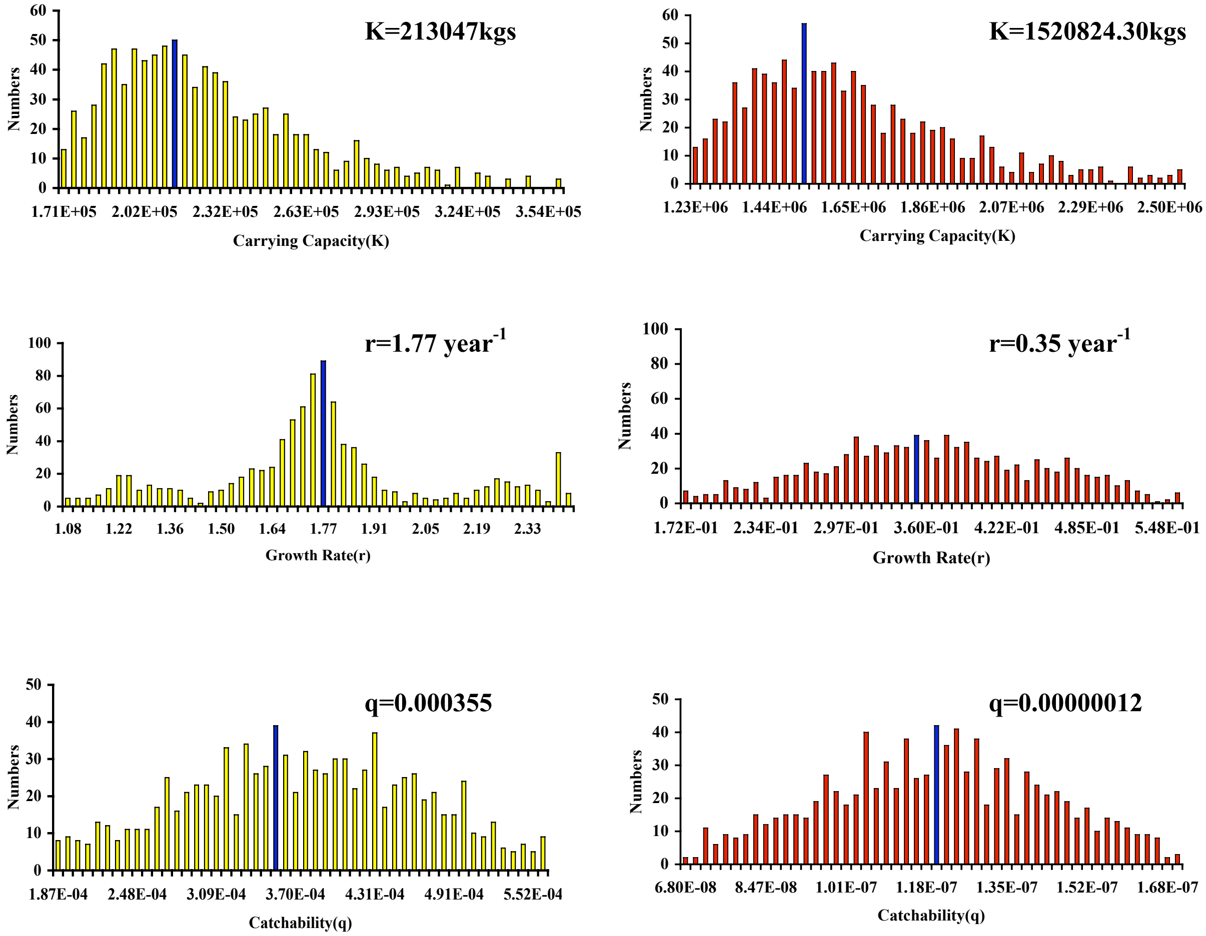


Figure 15. Likelihood profiles of the parameter estimates of the Schaeffer surplus production model (K, r, q) from the Bayesian method of fitting to catch and effort data of the commercial and municipal fisheries of the Lingayen Gulf from 1976-2004.

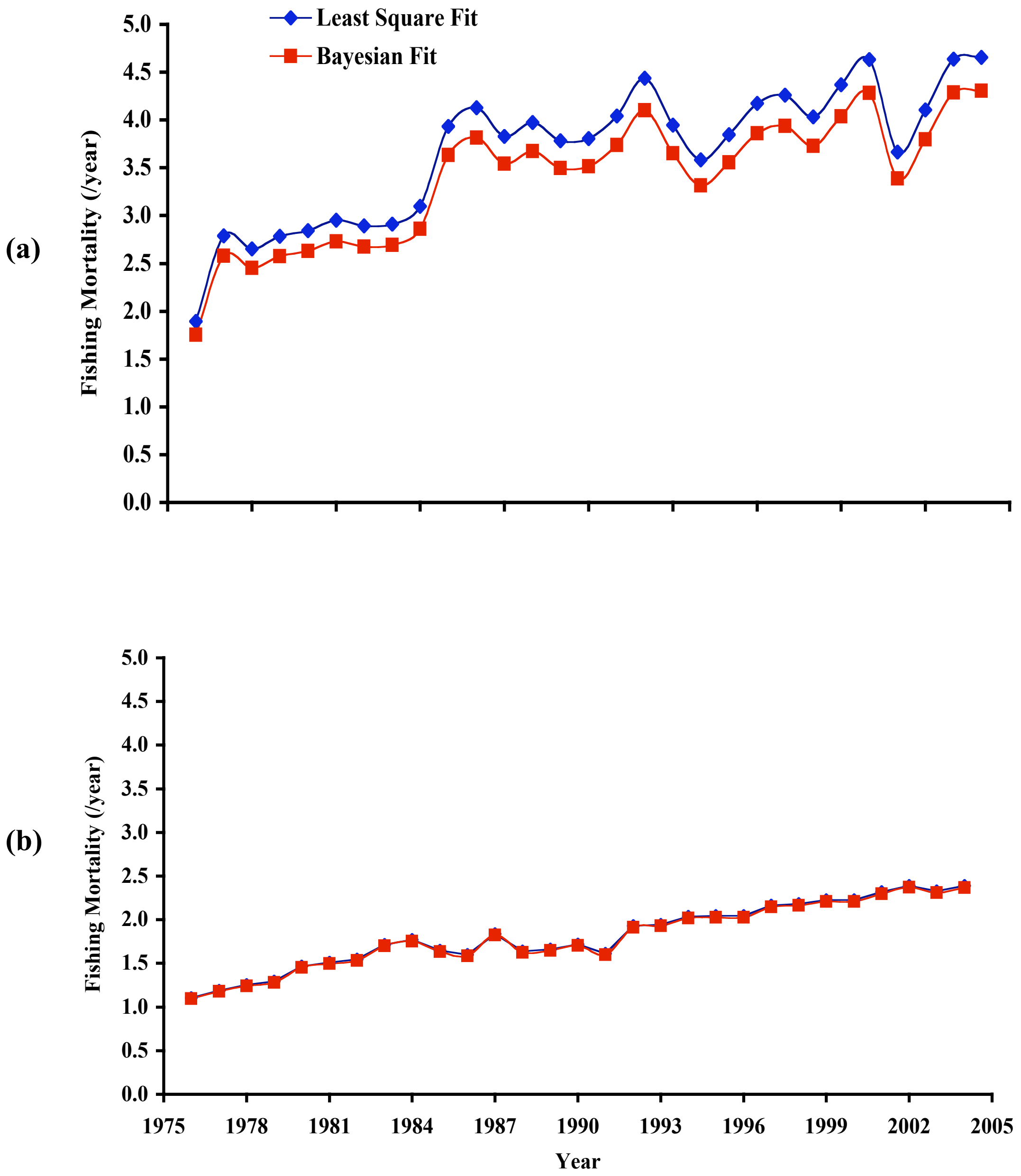


Figure 16. Predicted current fishing mortality rates ($F_{current}$) for 1976-2004 for the (a) commercial and (b) municipal fisheries of the Lingayen Gulf, Philippines based on the least squares and Bayesian fitting methods.

4. DISCUSSION

Data gathering necessary for many of the conventional stock assessment methods are frequently expensive and difficult to perform due to the complexity of species life-histories and the variety of harvesting methods (Gayanillo and Pauly 1997; Craig 1999; Froese and Binohlan 2003). Most stock assessment methods have been developed for temperate water species and are not directly applicable to tropical fisheries (Gayanillo and Pauly 1997). Institutions in developing countries do not have the resources to conduct the substantial biological and catch sampling and research that is necessary to apply the conventional methods, and while much high quality work is conducted in developing countries, often the time series of data available are too short to engender confidence in assessment results. What is needed is a stock assessment methodology that is tailored to the requirements of fisheries management in developing countries, and that is easily implementable (Sparre and Venema 1998).

4.1. Stock Assessment Methods

True length-based stock assessment methods are used when age data are impossible to determine (Pauly 1984; Gulland and Rosenberg 1992; Froese and Binohlan 2003). The methods rely on size to predict the growth and mortality of a certain population (Gulland and Rosenberg 1992). These types of methods are applied to mollusks and crustaceans such as abalone, clams, lobsters, crabs and shrimps where body parts such as otolith, scales and bone structures commonly use in determining age do not exist.

While most stock assessment methods are age-dependent the possibility of size or length-based stock assessment methods offers a potentially simpler and cheaper approach. The use of size or length-based methods was first introduced by Petersen in 1892 (Gulland and Rosenberg 1992; Gayanillo and Pauly 1997). The most common of his methods were the Petersen method and the modal progression analysis. These methods identify cohorts by the peaks in a time series of length-frequency histograms by assuming that individual cohorts result from separate spawning events. This limitation was overcome in the program ELEFAN by using the data itself to identify cohorts.

ELEFAN method has been criticized because, in some situations, inaccurate identification of the cohorts from the length-frequency data can occur, leading to incorrect estimates of growth and mortality rates (Jennings et al. 2001). Other criticisms of ELEFAN include that the method is computationally complex, model insensitive to change in input, and the output does not provide confidence intervals (Gallucci et al. 1997; Jennings et al. 2001). ELEFAN also lacks flexibility in model formulation. For example, ELEFAN should not be used to estimate growth parameters of long-lived, slow-growing species (Jennings et al. 2001).

The advantages of the ELEFAN method include its use of data that are easy to collect; input data requirements are simple (e.g. length-frequencies over time); results can be used to provide quick and easy information on how the basic growth and morality rates of the population of interest, and model output (e.g., K and L_∞) can be used as inputs to other population models to generate management relevant information (e.g. Beverton and Holt relative yield-per-recruit model). Clearly, the ELEFAN method offers a viable approach for data-limited situations, provided it is used with care and caution.

The MULTIFAN model is considered as a more sophisticated alternative to ELEFAN. MULTIFAN is more robust, statistically based, and makes use of time series of length-frequency data to provide estimates of the von Bertalanffy growth parameters and the relative age of the catch (Fournier et al. 1990). The disadvantage of the MULTIFAN model, however, is that it was designed for large-scale sampling of oceanic catches from commercial fisheries. MULTIFAN is best used for large, long-live, slow-growing species (Fournier and Archibad 1982; Fournier et al. 1990; Fournier et al. 1998), and has been used extensively for bluefin tuna, shark, blue marlin, and swordfish (Fournier et al. 1998). The current MULTIFAN model is not intended for use for short-lived coastal species (Fournier et al. 1998). Development of a version of MULTIFAN applicable for small-scale commercial fisheries is currently underway.

I used two alternative equations to estimate natural mortality rate, Pauly's (1980) equation and Beddington and Kirkwood's (2005) equation. Estimated natural mortality rates using Pauly's equation were, on average, higher by about 10% for moonfish and short mackerel and higher by about 35% for tropical anchovy (Table 5). Generally, the rate of natural mortality (M) is one of the most difficult parameters to determine for fish species (Gallucci et al. 1996). Truly direct estimates of M can only be achieved from long-term data on stocks under unfished conditions are available. Estimation of M is especially important for fast growing, short-lived species because their natural mortality rates are relatively high (Pauly 1980; Froese and Binohlan, 2000; Beddington and Kirkwood 2005). Typically, 95% of individuals spawned in short-lived species do not survive to the fishable size because of natural mortality only (Beverton 1990; Beverton 1992; Denney et al. 2002).

The most common method to predict total mortality (Z) using length-frequency data is the length-converted catch curve. This method is widely applicable because it makes use of time series of length-frequency data, and the assumptions and steps in the creation of the catch curve are generally considered biologically reasonable for many species (Gayanillo and Pauly 1997). Gulland and Rosenberg (1992) and Gayanillo and Pauly (1997) concluded that the length-converted catch curve provides the most reasonable estimate of total mortality from length-frequency data among the most commonly used methods (e.g., Beverton and Holt's method, Hoenig's method). One disadvantage of the length-converted catch curve approach is that it only makes use of the right-hand descending limb of the catch curve and thus provides estimates of total mortality only for individuals that are fully recruited to the fishery.

My difficulties in fitting the surplus production model to the commercial, and especially the municipal fisheries catch and effort data suggests that there are inconsistencies between the modeling approach and the data. These inconsistencies could relate to violations of assumptions, such as a closed population, that underlie the surplus modeling approach, inaccuracies in the catch and effort data (e.g., technological changes), and heterogeneity of the species and fisheries at the community-level.

Future analysis should emphasize the use of simulation to determine the accuracy and precision of ELEFAN to identify cohorts from limited data. The general approach would be to use a population dynamics model with protracted spawning and other life-history characteristics typified by the three species analyzed here. Under a variety of conditions, length frequencies would be generated with known parameters and then ELEFAN applied to the data to see if the estimated cohorts match the known cohorts.

4.2. Resilience and Other Qualitative Indicators

Musick (1999) proposed that basic life-history parameters could be used to qualitatively classify fish species into the categories of high, medium, low, and very low resiliency or productivity (Table 10). Resilience is the time required for a system to return to equilibrium or a steady-state following a perturbation. The measure of resilience is how far the system has moved from the equilibrium and how quickly it returns (Holling 1973; Gunderson 2000). My analysis provided estimates of three of the needed life history parameters (K, t_m and t_{max}, see Tables 2 and 4). Based on my analysis, moonfish, short mackerel, and tropical anchovy would be considered in the high resiliency category. Predicted growth rates (K) of the three species ranged from 0.50-1.70 per year and they matured within 10-12 months of being spawned ($t_m \leq 1$). Some caution is appropriate, however, because the longevity of the three species ($t_{max}=3-5$) was characteristic of the medium resiliency category.

Froese (2004) offered an approach involving three simple indicators that would allow for a qualitative assessment of the status of an exploited population that relied on life-history and growth rate parameters. The first indicator is described as "Let them spawn" and is measured by the percentage of mature individuals in the catch. The target would be to let all fish spawn at least once before they are potentially caught ($L_m < L_c$). Allowing spawning before harvesting could result in a healthy spawning stock especially for short-lived species. For the three species I analyzed, length at first capture (L_c in Table 4) was generally shorter than their length at first maturity (L_m in Table 2); however, length at first maturity is uncertain because it was indirectly inferred from other species. If my values for L_c and L_m are correct, then more than 80% of the individuals

Table 10. Life-history parameters suggested by Musick (1999) for classifying the resilience or productivity of fish populations (t_m=age at maturity; t_{max}=maximum age; K= growth rate; r_{max} =maximum intrinsic rate of growth of a stock; fecundity=potential reproductive capacity of organism or population expressed in the number of eggs or offspring produced during each reproductive cycle; threshold= levels of environmental indicators beyond which a system undergoes significant changes).

Parameter	Unit	Resilience			
		High	Medium	Low	Very Low
t_m	years	≤ 1	2-4	5-10	>10
t_{max}	years	1-3	4-10	11-30	>30
K	$year^{-1}$	>0.30	0.16-0.30	0.05-0.15	<0.05
r_{max}	$year^{-1}$	>0.50	0.16-0.50	0.05-0.15	<0.05
Fecundity	$year^{-1}$	>10000	100-1000	10-100	<10
Threshold		0.99	0.95	0.85	0.70

harvested for moonfish and short mackerel are harvested at a length below L_m. In the case of tropical anchovy, 100% of the observed length-frequency data of the catch is shorter than their estimated L_m. However, my estimated values of length at first maturity are uncertain because they were based on other species or indirect information. Based on this first indicator of “Let them spawn”, the three species analyzed here may be undergoing overfishing.

The second indicator proposed by Froese (2004) is described as “Let them grow” and is measured as the percentage of fish caught at the optimum length for harvesting. Optimal length for harvesting is defined as the length where the number of fish in a given unfished year-class, multiplied with their mean individual weight, is maximum and where the maximum yield and revenue can be obtained. Optimum length (L_{opt}) is typically longer than length at first maturity (L_m) and can be estimated from growth rate and mortality parameters with the equations provided by Froese and Binohlan (2000). The target would be to catch fish longer than the optimal length to let juveniles grow in weight and reproduce at least once before being harvested. My analyses of the three species did not include estimation of the optimal length of harvesting. However, given that most individuals in the catch were juveniles, it is likely that current harvesting of moonfish and short mackerel involves many individuals smaller than the optimal length at harvesting. If this is the case, then these populations are undergoing growth overfishing. Growth overfishing of tropical anchovy is also possible because its lengths at harvest appears to be small relative to length at maturity and therefore likely to be small than optimal length at harvesting, although the estimated harvesting rates for tropical anchovy are presently lower than the other two species.

The third indicator proposed by Froese (2004) can be described as " Let the mega-spawner live" and is measured as a percentage of old, large fish in the catch. The aim is to implement a fishing strategy that results in relatively few mega-spawners being caught. Large female are more fecund because the number of eggs increases exponentially with length and the eggs of older spawners tend to be larger and therefore perhaps more likely to survive (Solemdal 1997; Trippel 1998). Reaching old age is usually a sign of high overall individual fitness, and thus these mega-spawners are a reservoir for large numbers of eggs and perhaps good genes. Extending longevity and prolonging the reproductive phase can also be viewed as a safeguard against recruitment failure (Craig 1985; Beverton 1987). In most instances, it is desirable for 30-40% of the adult population to be old adults represent a healthy age structure and are desirable, whereas less than 20% maybe a matter of concern. My analyses of the three species suggest that the number of older adults or potential mega-spawner is very low. Most of the catch of the three species was represented by juveniles. Without catch at aged data, however, it is difficult to determine whether the age-structure of the catch is well-balanced. It is possible that the fishery gear selects for smaller individuals. Nevertheless, if the high proportion of juveniles in the catch of the three species reflects the lack of old adults in the population, then this would imply these species might be undergoing overharvesting.

Qualitative analysis using Musick's (1999) criteria suggests that moonfish, short mackerel, and tropical anchovy maybe highly resilient and would rebuild quickly to increased and high fishing due to their fast growth and high fecundity. Yet, Froese's (2004) indicators imply these species show signs of overfishing. High resiliency does not necessarily mean that the population is also highly resistant. High resistance means that impacts do not easily move the population away from its current state (Holling 1973; Gunderson 2000). Indeed, I suspect that while the three species analyzed here are highly resilient they also have low resistance, meaning they would be greatly affected by changes in fishing but can likely recover from such changes. Low resistance implies that these suggest that these species cannot withstand prolonged and continuous intensive fishing (NOAA 2005). The ability of small pelagic species to aggregate and form schools makes them very vulnerable to exploitation. Other stocks with similar life history characteristics, such as the Peruvian anchovy (Barrett et al. 1985) and Japanese sardines (Noto and Yasuda 1999), have collapsed in the past due to overfishing.

4.3. Quantitative Assessment of Harvesting in Lingayen Gulf

For the three species I analyzed, predicted fishing mortality rates are undoubtedly high and showed large interannual variability. The actual fishing mortality rates of moonfish and short mackerel during the five years (1998-2003) were typically around 3.0 year^{-1} (Table 6); fishing mortality rates of tropical anchovy were lower at 0.5 to 1.0

year^{-1}. Ingles and Pauly (1982) estimated the fishing mortality rate of the same three species in Lingayen Gulf for 1979 using length-frequency data. They estimated an averaged fishing mortality rate of 1.5 year^{-1}. While the methods I used differ from those of Ingles and Pauly (1982), it appears that the fishing mortality rates in the Lingayen Gulf have remained high or have increased since 1979.

I used a variety of methods to develop a weight-of-evidence analysis of the current fishing mortality rates relative to fishing rate at MSY. Based on my results using the life history invariant, length-based catch analysis, and individual-based population modeling methods, predicted fishing mortality rates of moonfish and short mackerel in the Lingayen Gulf likely are at or exceed F_{msy} values ($F_{current}$>F_{msy}, Figure 13a and 13b). These species are likely experiencing overfishing. Estimated current fishing mortality rates of tropical anchovy were lower than the other species but the harvesting of many juveniles and the general increasing fishing rates in the Lingayen Gulf also make their status worth monitoring. Because I did not analyze the current spawning stock biomass relative to biomass at MSY, I cannot determine if these species are overfished or not.

The question of which method produced the best (most accurate and precise) estimate of F_{msy} is a matter of choice. The order-of-magnitude similarity of results from the different methods is encouraging. However, all of these methods ultimately relied on von Bertalanffy growth rate parameters and identification of cohorts by ELEFAN. Thus, their agreement merits some confidence over each method individually, but does not merit the same confidence as if they were truly independent analyses. The extent of accuracy and reliability of these approaches are very promising and should not be taken for granted. A pilot study that includes ageing of one or more of these species would be very useful to confirm the veracity of these approaches.

The catch-per-unit-effort time series and the community-level fishing mortality rates predicted from the Schaefer surplus production model confirmed the perceived trend of generally increasing fishing mortality in the Lingayen Gulf. The effect of fishing in Lingayen Gulf has increased by at least 145% over the last 30 years (Talaue-McManus et al. 2001; Green et al. 2003). Further evidence is that catch-per-unit effort in the Gulf has dropped exponentially in recent years (Figure 9; Ochavillo et al. 19991; Green et al. 2003).

My application of the catch-related methods to each year separately and my use of alternative assumptions for natural mortality rates and for recruitment and spawning in the IBM provided a measure of the uncertainty associated with estimated F_{msy} values. The identification of cohorts from the catch data, which provided the basis of estimation the von Bertalanffy curve parameters and actual fishing mortality rates, was fundamental to all of the methods. Many of these growth and mortality parameters varied greatly from year to year, suggesting that my results were sensitive to the identification of cohorts in the catch data. F_{msy} values predicted by the IBM did not vary greatly under alternative assumptions of recruitment variability and steepness and whether new individuals spawn in the following year or not. Viewing my catch-related results and IBM results as averaged values over year-specific information is appropriate and hopefully makes my conclusions somewhat robust to errors in cohort identification. My use of multiple methods provides some sense of robustness, except that all of the species-specific analysis, including the IBM, relied to varying degrees on accurate cohort identification.

Uncertainty with cohort identification and the unknown openness of the Lingayen Gulf suggests a precautionary approach should be used.

I treated the population as closed. If fish in the Lingayen Gulf exchange with other areas, then my results would likely be conservative (perhaps overly conservative) for the species of interest. The Lingayen Gulf is not a closed system and the effects on the populations of high harvest within the Gulf could be dampened by fish in other areas continuing to contribute to stock productivity. The Lingayen Gulf has a mouth that connects to the South China Sea that serves as a crossroad for migratory fish (e.g. tuna, mackerel, anchovy, sardines). The degree of exchange of moonfish, short mackerel, and tropical anchovy between the Lingayen Gulf and the South China Sea is unknown. Because quantitative information on the degree of isolation of fish in the Lingayen Gulf is unavailable, I assumed that the catch in the Gulf were from a self-contained populations.

4.4. Implication to Fisheries Management in Lingayen Gulf

Overfishing in Lingayen Gulf is possible because of the *de facto* “open access regime” that has been in effect for the past decade. In an open-access fishery, any individual has the right to use the resource without fear of exclusion (DENR et al. 2001). The resource is open to everyone who desires to fish, with each fisher deciding on where to fish, when to fish, how many hours to fish, what fish to take, and what gear to apply (Green et al. 2003; DENR et al. 2001).

Overfishing is reached when the amount of fishing effort is beyond the biological limits of production and sustainability of the fish population (Green et al. 2003; Haddon 2001). One measure of overfishing, and the one emphasized here, is fishing mortality

Table 11. Indicators of potential overfishing in the Philippines and other fisheries (Green et al. 2003; DENR et al. 2001).

Indicator of Overfishing
• Increased catch of juvenile and lower value fish
• Changes in species composition
• Change in average size of the fish, change in total fish catch
• Change in catch-per-unit effort
• Increased use of fine-mesh nets
• Fishers spending more hours to catch fish
• Decline in the average income of the fishers
• Marked increase in illegal fishing and use destructive fishing methods
• Increasing conflict between municipal and commercial fishers
• Proliferation of fish aggregating devices
• Intrusion of commercial fishing boats to municipal waters
• Large increases in the price of first and second-class fish
• Increasing number of fishers traveling to distant fishing grounds
• Proliferation of fish traps along mangroves and rivers and absence of seabirds hunting for school of fish

rates exceeding the fishing morality at MSY (Figure 13). Green et al. (2003) and DENR et al. (2001) summarize other possible signs of overfishing (Table 11), some of which seem to be appearing in the Lingayen Gulf. It seems that fishers in the Lingayen Gulf have to spend more time in the sea than they did 50 years ago (Green et al. 2003). In recent years, there is a shift in the type of species harvested in Lingayen Gulf, with larger and slower growing species declining and fast growing, short-lived increasing. Anchovies have partially replaced sardines, and species like squid and cuttle fish have increased due to the reduced number of predatory fishes (Pauly et al. 1998; Pauly et al. 2000). The appearance of large number of jellyfish in recent years may also be an indication that the effect of fishing is relatively high and fishing is removing predators of the jellyfish (Pauly et al. 1998).

Hilomen et al. (2002) concluded that the Lingayen Gulf had reached its maximum sustainable yield more than 20 years ago and that the total commercial and municipal fishery has about 400% too much effort than can be sustained. These findings were solely based on the catch and effort data from commercial fisheries. Ingles and and Pauly (1984) earlier predicted that the fishing mortality of small pelagic species in Lingayen Gulf was 1.5year^{-1}. There approach, however, was based only on the length compositionof commercial catch. To date, there has not been an evaluation of the status of the commercial fisheries in the Lingayen Gulf that focused on using multiple approaches to compare estimated current rates of fishing mortality to estimated fishing mortality at MSY. Based on these earlier analyses, the fisheries of Lingayen Gulf have already been overfished. My analyses that focused on current fishing rates and fishing mortality at MSY further confirm the findings of the earlier analyses that only used catch. The current fishing mortality rates, especially for moonfish and short mackerel are high and higher than the fishing mortality rates at MSY. As such, there is a need to regulate and reduce the current commercial fishing mortality rates on small pelagic species in the Lingayen Gulf.

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