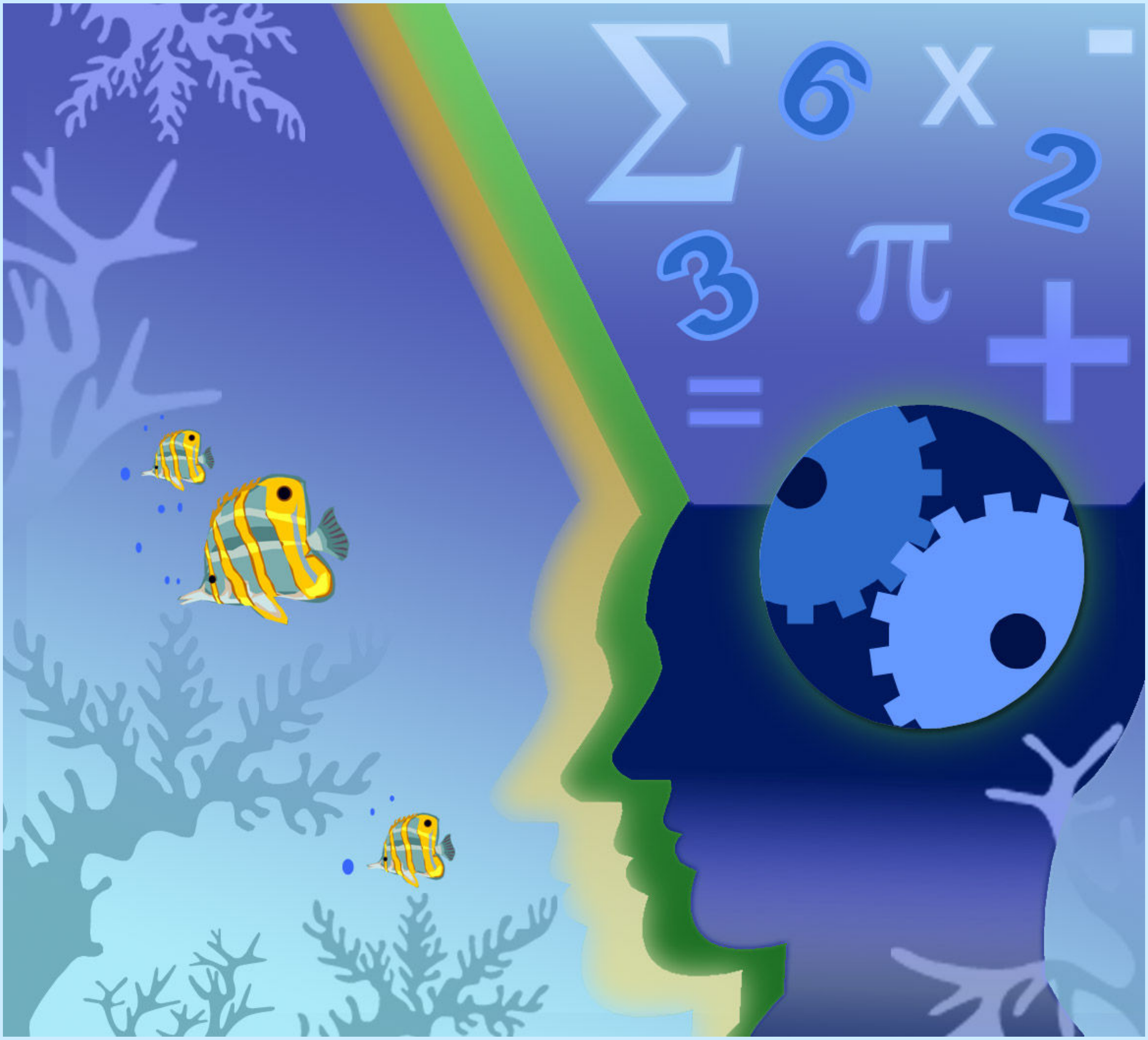

MAQTRAC

Marine Aquarium Trade Coral Reef Monitoring Protocol

Data Analysis and Interpretation Manual

Domingo Ochavillo and Gregor Hodgson

November 2006

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With transition matrix model for coral population trajectory analysis
by Dr. Wilfredo Licuanan

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Acronyms

CITES	Convention on the International Trade in Endangered Species of Wild Flora and Fauna
CPUE	catch-per-unit-effort
ELEFAN	Electronic Length-Frequency Analysis
FiSat	FAO-ICLARM Fish Stock Assessment Tools
MAC	Marine Aquarium Council
MAQTRAC	Marine Aquarium Trade Coral Reef Monitoring Protocol
MSY	Maximum sustainable yield
SC	size class
SPR	Spawning Stock Biomass Per Recruit
TAC	Total allowable catch
VPA	Virtual Population Analysis
YPR	Yield-per-recruit

Background ....

chapter 1

The ornamental trade is a rapidly expanding industry that sources a high percentage of organisms from the often overfished and degraded coral reefs of the Philippines and Indonesia. There is a potential threat for collection to drive local populations to unviable levels. If the trade is to be sustainable, catch limits constitute an important management strategy in addition to the establishment of no-take marine protected areas and other coral reef rehabilitation activities.

This Data Analysis and Interpretation Manual of the Marine Aquarium Trade Coral Reef Monitoring Protocol (MAQTRAC) is an accompanying volume to the MAQTRAC Field Operations Manual. This manual has been developed as a guide for scientists to be able to analyze ornamental fisheries with limited historical data and to set total allowable catch limits for targeted ornamental populations. The concept of total allowable catch (TAC) is a new concept for the ornamental fishery in both the Philippines and Indonesia.

Total Allowable Catch as a Reference Point

'Reference points' such as total allowable catch are used to manage a fishery. A reference point is defined as a value derived from technical analysis to manage a stock (Caddy 1998). Reference points are largely based on models that are mathematical conceptualizations of the populations of target species. In practical terms, these reference points may have a poorly-defined level of error. The determination of reference points to manage fisheries has been difficult even in developed countries that have invested substantial time and finances on research. The difficulties have been largely due to errors at different levels: (1) process errors due to nature's variability; (2) measurement error; (3) model uncertainties; and (4) estimation error due to combinations of the above factors. For example, due to the cryptic nature of various ornamental species it can be assumed that MAQTRAC surveys produce conservative estimates of stock abundances therefore giving conservative estimates of population abundances. Even among highly visible ornamentals, the physical complexity of coral reefs provides hiding places further leading to underestimates of abundance.

Developing technical reference points for the aquarium trade is challenging because it is a multi-species fishery, and there is very little information regarding historical catch and effort and on the ecology of the target species. The development of reference points for the ornamental trade requires a combination of traditional fisheries models, practical guidelines and most importantly, empirical experience, that can de derived from an adaptive management approach.

Total allowable catch developed for the aquarium trade can be used to provide interim reference points that will be subsequently refined as more data are gathered. Annual target population surveys are required as part of the Ecosystem and Fisheries Management standard under the MAC certification program.

Determining Total Allowable Catch for Fish and Invertebrates Other than Corals ....

chapter 2

In cases where long-term catch records are not available, total allowable catch can be estimated from natural mortality rates. In cases wherein catch records are available, yield-per-recruit analysis can be used. Both methods can also be used to estimate a range of catch limits. (See Appendix 1 for a review of fisheries models and their applicability to ornamental fisheries). The following is a diagram of the flow of analysis and the subsequent determination of total allowable catch.

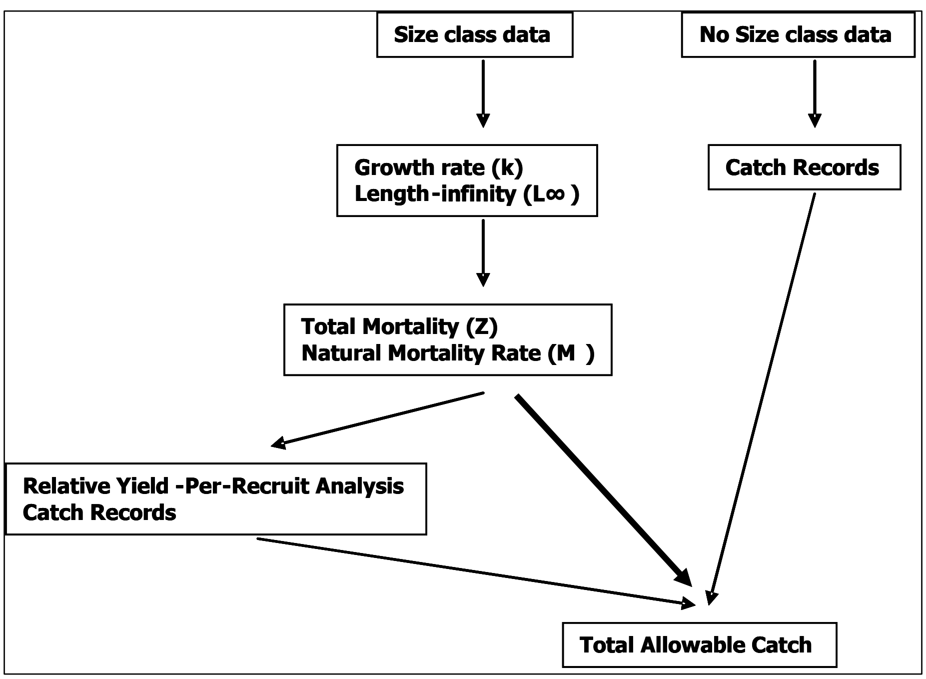

Figure 1 Flow of data analysis for ornamental fish and invertebrates

2.1 Natural mortality and Yield-per-recruit case studies (central Philippines data)

Population parameters (growth, mortality and relative yield-per-recruit estimation) were derived for various species that had representative size class data using FiSat software. (The FiSat software can be downloaded free of charge from the website http://www.fao.org/fi/statist/fisoft/fisat/downloads.htm.) To be representative, the analysis requires size class data from recruits, juveniles and adults of a minimum of 150 individuals. Typically, it is NOT possible to obtain this number of observations from a single population of aquarium fish species such as the Emperor Angelfish, therefore other methods must be used. But for naturally abundant species such as Green Chromis, these data provide a view of the population growth trajectory which is the basis for this type of stock assessment. Length-at-first capture data (the smallest size of the species collected in the trade) were obtained from catch records of collectors. The latter data are important in relative yield-per-recruit analysis.

A step-by-step list is given below regarding how to calculate natural mortality and analyze relative yield-per-recruit for fish and invertebrates (except corals) using FiSat software. Corals require a different approach.

1. Obtain size class data for a species including recruits to adults with a total of 150-200 individuals. The data are input to the FiSat software for the following steps.
2. Divide the size data into several classes. We recommend a 1 cm interval for damselfish size classes and for other fishes that have a maximum size of around 5 to 6 cm; 2 to 3 cm size class intervals for anemonefishes; 3 to 4 cm size class intervals for butterflyfishes and other fishes that have a maximum size from 15 to 20 cm; and 5 cm groupings for the bigger angelfishes (e.g. *Chaetodontoplus mesoleucus*) and other fishes with maximum size more than 20 cm. (Encode data in the necessary query in FiSat.);
3. To estimate the growth coefficient k and L-infinity, go to (a) Assess query; (b) to direct fit of length frequency data; (c) to ELEFAN 1; and then (d) k scan;

4. To estimate total mortality rate (Z), go to (a) Assess; then to (b) Mortality Estimation; then to (c) Z from steady-state sample; then to (d) Length converted catch curve; and then to (e) Catch Curve;

5. To estimate the natural mortality rate (M), go to (a) Assess; then to (b) Mortality Estimation; then to (c) Natural Mortality; and then to (d) Pauly's M equation. Use 28^0C for temperature in tropical situations. The inverse of the natural log of natural mortality M is a provisional catch limit estimate, and is expressed as a percentage of the standing stock.

For a fishery with historical catch records proceed to yield-per-recruit analysis:

6. Calculate separately the ratio of M/k and l_c/L-infinity. The number l_c (length-at-first-capture) is the smallest size collected for that species in the ornamental trade.

7. For relative yield-per-recruit analysis, go to (a) Assess; then to (b) Beverton-Holt Y/R Analysis; then to (c) Knife-edge; and then (d) fill-in the value M/k and l_c/L-infinity.

8. Note the reference point E-10, the exploitation rate reference point.

Natural mortality (M) rates in relation to stock abundance were derived for several ornamental target fish and one invertebrate (the blue sea star) in the central Philippines using growth rate (k) and L values using the FiSat software (Table 1). These natural mortality rates in relation to the population can be used as species-specific reference points. When data are lacking, the natural mortality rate of one species can be used as an estimate for other similar species from the same families and/or ecologically-similar species with inadequate size class data.

In general, the results indicate trends of relatively smaller fish species (based on $L\infty$ comparisons) having higher growth rates (k) than relatively larger ones (e.g. *Amphiprion clarkii* versus *Chaetodontoplus mesoleucus*) (Figure 2). These smaller-sized fish species also have higher natural mortality rates.

Table 1: Natural mortality rates (M), growth rates (k) for eight fish and one invertebrate.				
Species	**Group**	**k**	**L-infinity (cm)**	**M**
Premnas biaculeatus	*Fish*	1.3	17.85	2.45
Amphiprion ocellaris	*Fish*	1.6	6.83	3.67
Amphiprion clarkii	*Fish*	1.8	13.13	3.3
Dascyllus aruanus	*Fish*	1.3	6.83	3.2
Bodianus mesothorax	*Fish*	1.4	23.1	2.39
Chaetodontoplus mesoleucus	*Fish*	0.92	27.3	1.65
Cheilodipterus quinquelineatus	*Fish*	1.5	9.98	3.16
Chelmon rostratus	*Fish*	1.4	20.48	2.47
Linkia laevigata	*Invert.*	1.3	39.9	1.96

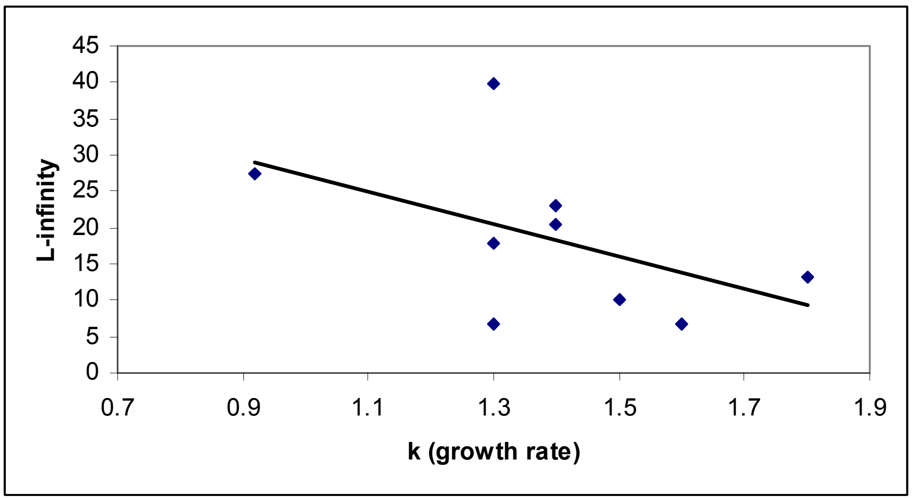

Figure 2 *Inverse relationship between growth rate (k) and L-infinity.*

The results below indicate that the total allowable catch based on natural mortality rates roughly reflect the relative abundance of these target ornamentals in coral reefs (Table 2). The results shown in Table 3 results indicate a good rule-of-thumb of collection limits. However, mortality rates may vary with specific areas so growth rates and L-infinity should still be determined whenever possible.

Table 2: Relative abundance of four fish families for four collection areas surveyed in the Philippines.

Family	Common name	% relative abundance
Pomacentridae	Damselfishes	80
Labridae	Wrasses	13
Chaetodontidae	Butterflyfishes	5
Pomacanthidae	Angelfishes	2

Table 3: Proportion of populations of ornamentals suggested as sustainable collection levels based on estimated natural mortality rates.

Species	Common Name	TAC As % of Pop.
Amphiprion clarkii	African Clownfish	25
Amphiprion frenatus	Tomato Clownfish	25
Amphiprion ocellaris	False Percula Clownfish	25
Amphiprion perideraion	Pink Skunk Clownfish	25
Balistoides viridescens	Titan Triggerfish	10
Bodianus axillaris	Axilspot Hogfish	10
Bodianus diana	Diana Hogfish	10
Bodianus mesothorax	Coral Hogfish	10
Centropyge vroliki	Halfblack Angelfish	5
Chaetodon adiergastos	Panda Butterflyfish	15
Chaetodon baronessa	Baroness Butterflyfish	15
Chaetodon bennetti	Bennett Butterflyfish	15
Chaetodon melannotus	Blackback Butterflyfish	15
Chaetodon octofasciatus	Eight Banded Butterflyfish	15
Chaetodon rafflesi	Rafflesi Butterflyfish	15
Chaetodon speculum	Ovalspot Butterflyfish	15
Chaetodon trifasciatus	Melon Butterflyfish	15
Chaetodontoplus mesoleucus	Queen Angelfish	5
Cheilio inermis	Cigar Wrasse	10
Cheilodipterus quinquelineatus	Fivelined Cardinalfish	20
Chelmon rostratus	Chelmon Butterflyfish	10
Coris gaimard	Red Wrasse	10
Dascyllus aruanus	Three Damselfish	20
Dascyllus reticulatus	Reticulated Damselfish	20
Dascyllus trimaculatus	Domino Damselfish	20
Gomphosus varius	Green/Brown Bird Wrasse	10
Halichoeres chloropterus	Green Wrasse	10
Halichoeres hortulanus	Marble Wrasse	10
Hemigymnus melapterus	Black Eye Thicklip	10
Heniochus acuminatus	Black & White Heniochus	10
Heniochus chrysostomus	Brown Heniochus	10
Heniochus varius	Fake Heniochus	10
Pomacanthus sextriatus	Sexbarred Angelfish	5

Pygoplites diacanthus	Regal Angelfish	5
Thalassoma lunare	Moon Wrasse	10
Zanclus cornotus	Moorish Idol	10
Zebrasoma veliferum	Sailfin Tang	10

The following tables show the results for natural mortality estimation and the relative-yield-per-recruit analyses for several ornamental target fish species in Batasan Island and nearby reefs, Bohol province, central Philippines:

Table 4: Population parameters, extraction rates and TACs for various ornamentals in central Philippines.

Species	k	L∞	M	E	E-10	Maximum Recorded Annual Catch	TAC
Premnas biaculeatus	1.3	17.85	2.45	0.16	0.307	5129 (in 2002)	9841
Amphiprion ocellaris	1.6	6.83	3.67	0.31	0.361	613 (in 2005)	712
Chaetodontoplus mesoleucus	0.92	27.3	1.65	0.23	0.413	560 (in 2002)	998
Chelmon rostratus	1.4	20.48	2.47	0.26	0.402	1850 (in 2004)	2846

Ideally, relative yield-per-recruit analyses are derived from numerous annual surveys. Total allowable catch is estimated from these analyses together with catch records. If annual catch records are available, the numbers corresponding roughly to the extraction rates at E-10 would be the total allowable catch (assuming linear relationships). Relative yield-per-recruit analyses assume populations at equilibrium. This is a constraint given the dearth of historical catch data in the aquarium trade. What is currently indicated as unsustainable extraction rates may be due to collection levels several years before especially in a target species that is relatively long-lived.

The exploitation rates were then compared to the maximum recorded annual catch from 2002 to 2005. The estimates of total allowable catch based on the relative yield-per-recruit analysis are shown in Table 4. The TAC was derived from proportional relationships of exploitation rate (E), maximum catch, and E-10. For example, the clownfish *Premnas biaculeatus* TAC was estimated in relation to E-10 (the sustainable exploitation rate) and to the proportion of E to maximum recorded catch.

TAC for the clownfish *P. aculeatus*:

$$TAC = (5129 * 0.307) / 0.16$$

In this case, the TAC for *P. aculeatus* was calculated as 9841.

Catch-Per-Unit Effort (CPUE) Data ………………….

chapter 3

Ornamental fishing is a highly targeted activity. Each week, fish buyers will send a list of their fish orders to the fishermen. This will be a subset of a long list of available target species. Fishermen only catch what is ordered and in specific quantities. However, some species are always high in-demand so these will be collected routinely during a typical fishing trip.

The catch-per-unit-effort (CPUE), usually expressed in number or weight of fish per unit time spent fishing per fisherman, is a useful indicator that can be used to manage a fishery. If a fishery is overfished, and the efficiency of the fishermen is constant, then over time, the CPUE would be expected to decline as it takes increasing amounts of time to catch the same number of fish. CPUE is thus a proxy estimator of species abundance. However, in cases where very low numbers of fish of a given species are ordered, the use of CPUE may be misleading due to relatively few data.

CPUE is an important monitoring tool in MAC certified collection areas due to the relative ease with which data can be collected. It is a complementary tool to compare with changes in temporal abundance as determined from MAQTRAC surveys. It is the primary tool for very cryptic species that are not recorded during MAQTRAC surveys. Under MAC certification, coordinators are required to maintain a log of the number organisms caught during a recorded period of time in a particular collection site. In practice fishermen may be reluctant to reveal exactly where they were fishing.

Assessment of the collectors' CPUE over time (over multiple reproductive periods) should provide a reasonable metric from which the status of the fishery can be gauged. Sudden or significant declines in CPUE may indicate potential overexploitation that can be assessed with additional MAQTRAC surveys. It is important to note that CPUE will vary widely between collectors, locations and perhaps seasonally. **As a practical management tool, a decline in CPUE should be used to trigger a recommendation for a proportional reduction in exploitation rates. For example, a decline of 30% in the CPUE of an ornamental target should lead to a decrease in fishing effort by 30% until CPUE can be stabilized.**

3.1 CPUE case studies (Batasan Island and nearby reefs, central Philippines)

CPUE, defined as the number of fish collected per hour by a collector, was determined for three species based on logbook data from Batasan Island, Municipality of Tubigon, Province of Bohol, Philippines for several months in 2002 and inter-annually from 2002 to 2005. The number of individual fish as recorded in the logbook was divided by three hours (the average fishing period in the village). Each collector had individual catch records so CPUE was expressed per unit fisherman. CPUE was determined for one of the most commonly caught fish, the butterflyfish *Chelmon rostratus*. This is a species that is always in high demand. The intra-annual trends in catch-per-unit effort constitute an important guideline as to whether collection can still continue in the short term. The inter-annual trends in catch-per-unit effort are important indications of total allowable catch especially for highly cryptic species like the mandarinfish *Synchiropus splendidus* and the banded shark *Chiloscyllium puntatum*. The latter is collected as juveniles and eggs.

The CPUE trends within 2002 for the chelmon butterflyfish are shown in Fig. 3. There were high levels of CPUE during May to June, September and during December in 2002. These trends may be due to increased abundance of these target ornamentals (following known recruitment periods from March to April and from August to September in the Philippines) and/or increased orders from markets in Europe and the U.S. Traditionally, trade trends indicate higher orders during winter months from these markets.

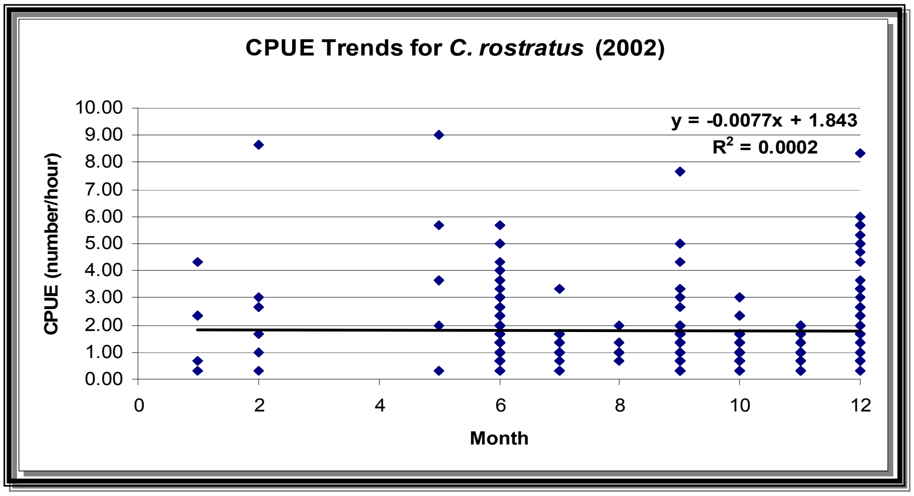

Figure 3 CPUE trends for the butterflyfish *C. rostratus* in Batasan, Bohol, Philippines

Inter-quarterly analyses of means should also be used for CPUE analysis for resource management decisions at a secondary level. The third and fourth quarter data were selected for analysis for this example because of the availability of several data points. In this analysis, the means between the two quarters actually increased so the collection continued. On the other hand, any significant decline between quarters should lead to a proportionate decrease in fishing effort (e.g. number of chelmon to be collected) for the next quarter. For instance, any significant 50% decline in the mean CPUE analysis should result to the decrease of number of chelmon butterflyfish that can be collected by 50% in the next quarter.

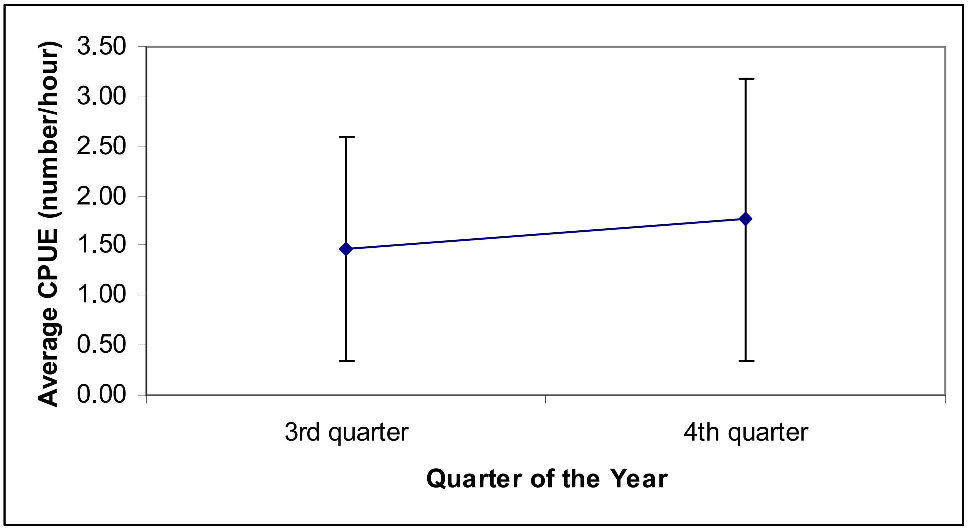

Figure 4 Inter-quarterly mean CPUE analysis for *C. rostratus* in Batasan, Bohol. The analysis did not indicate any decline so collection was allowed to continue.

CPUE as estimator of TAC for cryptic species

Inter-annual trends in catch-per-unit effort together with historical catch records can be used as rough estimates of total allowable catch for highly cryptic species. The figures below show large annual variation, but no declining trend for any species over the four-year period. Therefore, it appears that these exploitation rates are sustainable, and the mean of annual catch has been chosen as the provisional TAC. The banded shark (both juveniles and eggs) was used as an example here because sufficient data are available. However, this species should be assessed on its suitability for trade given the shark's low fecundity and inappropriate size for most aquarium keeping.

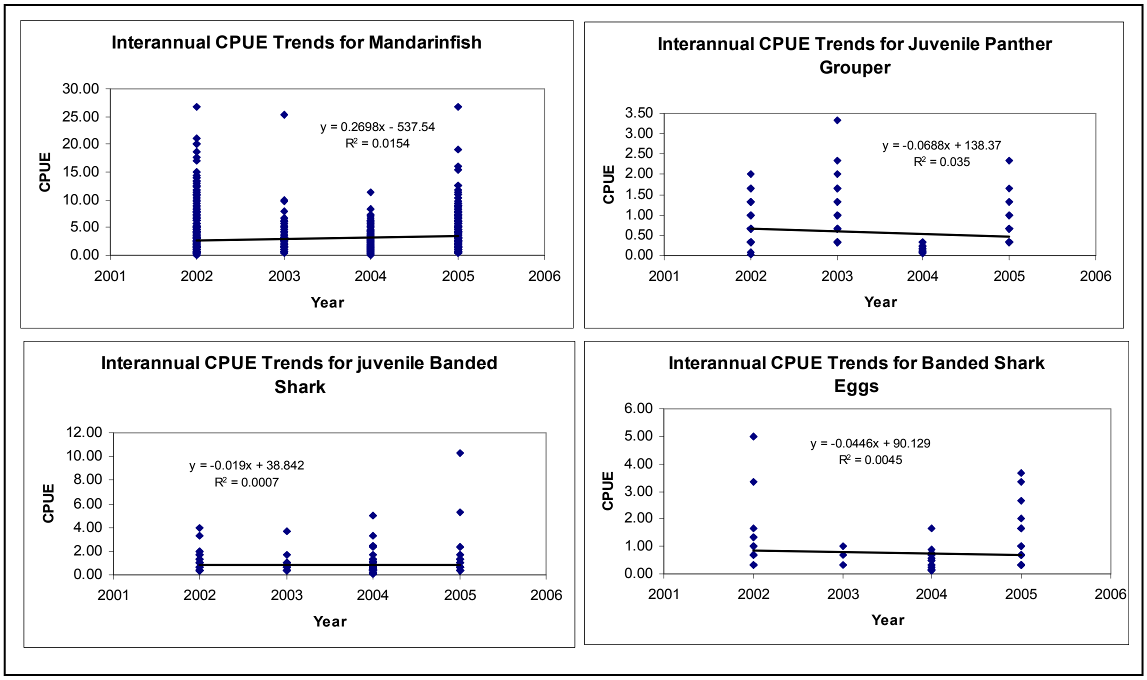

Figure 5 Inter-annual trends in catch-per-unit effort for various ornamentals in central Philippines.

Based on the above data and historical catch records, we have the following recommendations for annual TACs specifically for the reefs in Batasan island and the vicinity:

1.) For the highly cryptic mandarinfish *Synchiropus splendidus*, we recommended total annual catch to be 5000 individuals based on catch records and trends in CPUE for the Batasan reefs with an area of 24 km^2.

2.) For the juvenile banded shark *Chiloscyllium punctatum*, we recommended TAC at 350 individuals per year based on catch records and trends in CPUE. We recommended collection of eggs at 100 per year based on no significant decline during 2005. However, we have also recommended that this species be assessed regarding its suitability for collection. Banded sharks are targeted as juveniles and eggs, a practice that might lead to growth overfishing. This shark also has low fecundity and grows to a size that cannot be easily maintained by hobbyists in home aquaria.

3.) For the panther grouper *Cromileptis altivelis*, we recommended annual collection of 300 based on intra- and inter-annual trends in catch-per-unit effort. This ornamental is targeted as a very young juvenile and adults are not commonly recorded. High collection might cause growth overfishing. The CPUE data indicated a decline in 2004 (see Figure 5). In hindsight, collection should have decreased in the early quarter of 2004 following the relatively higher mean in 2003. Fortunately, CPUE increased again in 2005.

Matrix Population Models & Coral Collection

chapter 4

Coral reefs are subject to a range of natural and man-made disturbances, from blast fishing to coral bleaching. As an added disturbance and as a fishery, coral collection should be managed in order not to aggravate the effects of these disturbances on reefs. Coral collection should not be allowed on reefs that have experienced bleaching events and/or heavily impacted by other disturbances such as storms, blast fishing and crown-of-thorns starfish infestation. Collection levels should also be set to make sure that at least the local population has the capacity for replacement and regeneration. This is important since many corals targeted by the aquarium trade are slow-growing.

Unlike other exploited stocks such as cod or salmon, few analogous fisheries models have been applied to corals as a management tool. A few of the traditional fisheries models were applied only to a limited extent to corals (e.g. mushroom corals). For example, Ross (1984) used yield-per-recruit analysis to determine the ecologically sustainable size of *Pocillopora damicornis* coral that is collected in the aquarium trade. The dearth of tools for coral fisheries is understandable because their collection does not have a long history unlike temperate fish stocks such as cod and haddock. Countries faced with developing quotas have used a variety of methods to try to derive them. In Indonesia, coral quotas are estimated mainly from trade data.

Matrix models, as a predictive tool, may be applicable to the coral ornamental trade management as a population-based framework especially in setting catch limits. Matrix models provide opportunities to project short-term and long-term changes relevant in coral populations under different mortality (with or without collection), growth and recruitment rates and thus provide basis for estimating sustainable collection levels. These models also incorporate individual shrinkage rates in these modeled populations. This is critical since size in corals does not necessarily approximate age due to interactions (that can lead to shrinkage) with other potentially space-limited and relatively immobile organisms (e.g. Hughes 1984). Modeling the effect of collection is analogous to the studies of Done (1987, 1988) that predicted the effects of natural disturbance (e.g., *Acanthaster planci* infestation) on the populations of *Porites* spp.. Coral collection for the ornamental trade is an additional disturbance and can be factored in as increased mortality rate.

Operationally, the transition matrix defines the probability that colonies in a particular size will grow into a larger size class, remain in the same size class, die, or shrink/break into a smaller size class. The probabilities in the diagonal of the size-classified matrix are the likelihoods of individuals in a given size class to remain in the same size class; below the diagonal are probabilities of growth to larger size classes; and those above the diagonal represent shrinkage to smaller size classes. Contribution to total recruitment of reproducing size classes are indicated and included in the first row of the matrix (see Table 7). The transition matrix is multiplied by the vector that is the observed size frequency distribution in the population under study.

4.1 *Anacropora matthaii* case study in Lampung, south Sumatra (Indonesia)

The changes in the populations of *Anacropora matthaii* in Lampung, south Sumatra in Indonesia were modeled to estimate sustainable levels of collection. The data were collected during MAQTRAC surveys conducted in 2004. Lampung is an important source of corals in Indonesia for international and local trade. For the data analysis, coral colonies were grouped according to size categories used by the ornamental trade: small (5.0 cm), medium (5.1 to 15.0 cm), large (15.1 to 25.0 cm) and extra large (> 25.0 cm.).

Ideally, the transition matrix should have probabilities of shrinkage, growth, and non-growth and estimates of contribution of each colony to recruitment (sexual and asexual), all of which are empirically-derived. However, in most cases such data are lacking. For the Lampung case study, we estimated probabilities of survivorship based on observed distribution of size classes. This assumes a steady-state condition for the population. In addition, we estimated contribution of each colony to recruitment by assuming that all corals in the smallest size class were products of the adults in the area

The following are the data used for modeling population changes for *A. matthaii*:

Table 5: Size class data of *A. matthaii* in Lampung, Indonesia.		
Category	**Size class**	**Number**
SC 1	≤5 cm	121
SC 2	5.1 to 15 cm	125
SC 3	15.1 to 25 cm	4
SC 4	> 25 cm	0

The data for *Anacropora matthaii* indicated that there were 121 colonies that were 5.0 cm and smaller (SC1); 125 colonies that were between 5.0 and 15.0 cm (SC2); 4 colonies between 15.0 and 25.0 cm; and no colonies above 25.0 cm.

Assumptions:

1.) Corals of sizes 5 cm and smaller are the recruits to the population (e.g. Chiappone and Sullivan 1996, Edmunds 2000).

2.) Colonies within size classes SC2 and SC3 contribute equally to recruitment (e.g. Chiappone and Sullivan 1996, Edmunds 2000). This assumes a degree of closure in the population population in the absence of data on how much the local and external populations are contributing to recruitment. Chiappone and Sullivan (1996) showed evidence of possible self-recruitment of both brooding and broadcast spawning corals in the Florida Reef Tract.

The following is a step-by-step guideline in using matrix models for *A. matthaii* data:

1.) Calculate the contribution of mature colonies to recruitment (first row of the matrix):

a.) Transform all data to natural logarithm. Take the sum of the log-transformed data for the sexually mature size classes (SC2 and SC3). Calculate the ratio of the log-transformed abundance of size class SC1 (recruits) to this sum.

2.) Calculate survivorship rate:

a.) Derive the slope of natural log-transformed abundance data by imposing a trendline in the graph option of any spreadsheet program. This slope is the instantaneous mortality rate. The inverse of this number is the mortality rate in %. The complement of this number is the survivorship. For example, the instantaneous mortality rate was 1.7 or 6% in *A. matthaii.* The survivorship was estimated at 94%.

b.) Derive size-specific (of the target size category 5 to 15 cm to the next size class) survivorship rate separately from the slope of the log-transformed data of the size classes of interest (SC2 and SC3) as described above. The rate of survivorship from SC2 (the target coral size) to SC3 was estimated to be 68 % (comprising both natural and fishing mortality).

3.) Calculate the probability of growth to the next size class:

a.) In this case, the probability of growing from SC1 to SC2 was 100%; from SC2 to SC3 was 66% growth probability based on data from Gomez et al. 1985.).

The following table is a rough guide for growth probability values for fast and slow-growing corals:

Table 6: Recommended probabilities of growth to next size classes in scleractinian corals (based in Gomez et al. 1985).

I. Fast-growing corals (e.g. *Acropora* spp.)

	SC1	**SC2**	**SC3**	**SC4**
SC1	***			
SC2	1	***		
SC3	***	0.66	***	
SC4	***	***	0.66	***

II. Slow-growing corals (e.g. *Goniopora* spp.)				
	SC1	**SC2**	**SC3**	**SC4**
SC1	***			
SC2	0.8	***		
SC3	***	0.3	***	
SC4	***	***	0.3	***

4.) Calculate the probability of growing and surviving to the next size class:

a.) The probability of growing to the next size class is a combination of the probability of survivorship and the growth rate of the coral species. These were estimated from steps 2 and 3. In this case, the probability of growing to the next size class was estimated at 94% from SC1 to SC2 with growth probability at 100% and survivorship at 94%; 45% from SC2 to SC3, based on 68% survivorship rate and 66% growth probability based on data from Gomez et al. 1985.).

Table 7: Derived transition matrix for the *A. matthaii* population in Lampung, Indonesia.			
	SC 1	**SC 2**	**SC 3**
SC 1	0.000	0.700	0.700
SC 2	0.94	0.000	0.000
SC 3	0.000	0.45	0.000

5.) Run the transition matrix model. For *A. matthaii,* the model indicates that the collection level is not sustainable given 68% survivorship of the targeted size (SC2) to the next size class (SC3) and with growth probability at 66%.

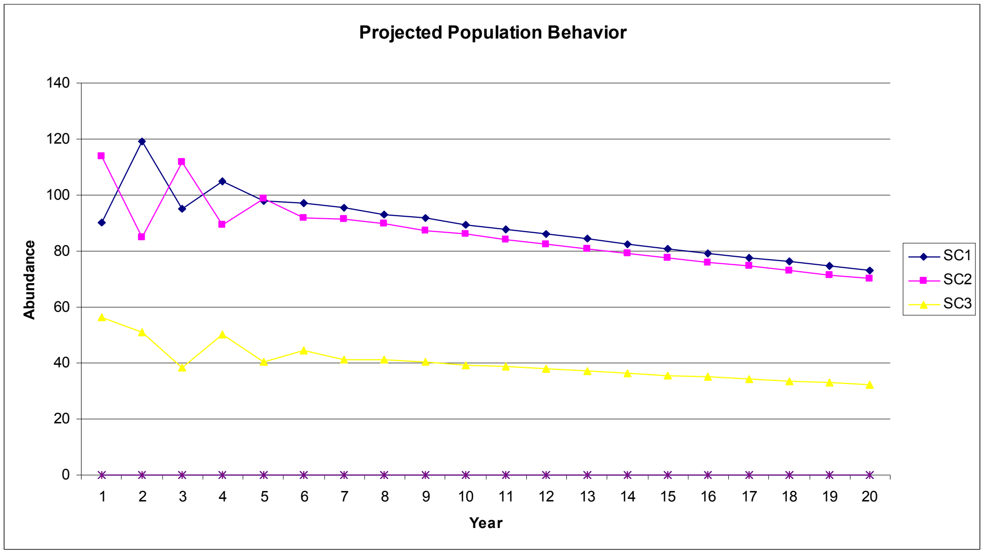

Figure 6 Population trajectory analysis for *A. matthaii* using the matrix transition model.

6.) Calculate TAC as % of the population by successively decreasing (from 100%) the probability of survivorship until the lambda, λ, (the index of the ability of the population to replace itself) gets to less than 1 at 20 years period. For example, in *A. matthaii* at 85% survivorship of the target class SC2 to SC3, λ is 1. At lower survivorship, λ is below 1. Therefore, 15% of SC2 abundance is the TAC for *A. matthaii* in Lampung. This absolute number can be derived from the average density (with upper limit) and estimated coral reef area. There is a caveat to this TAC as % of the population. This assumes that what is collected as TAC already incorporates the natural mortality rate. Simply, you collect including those what were supposed to die.

Operationally, the transition matrix is multiplied to the size classes iteratively and the changes in population are predicted. The predicted changes of the *A. matthaii* population in Lampung based on the size-class data and assumptions on its vital statistics are shown below. The results indicate that harvesting 15% of the abundance of the size class SC2 of *A. matthaii* in Lampung still maintains the population's ability to replace itself. Therefore, TAC as % of the population has to be below 15%. In this case we recommend 10%.

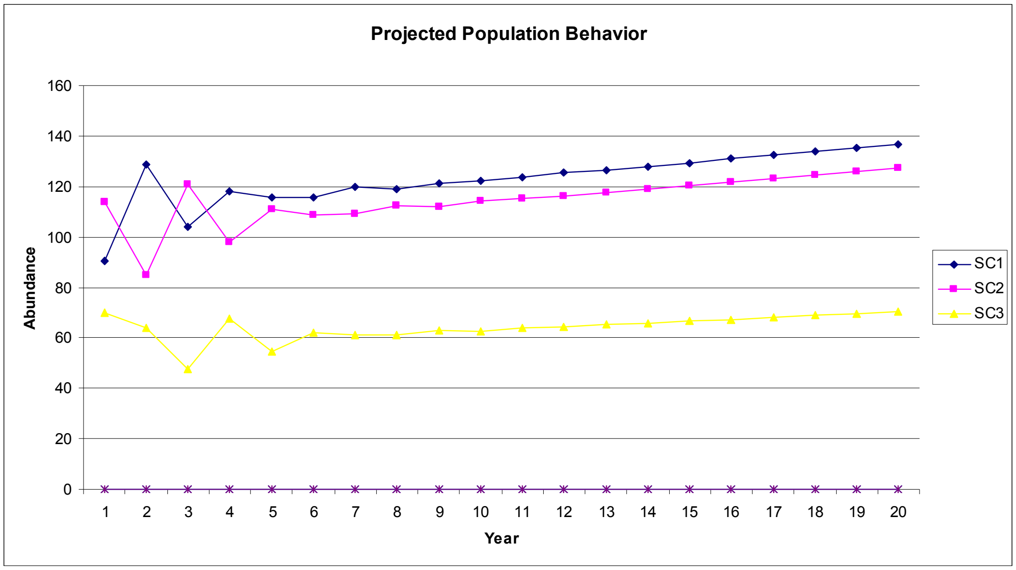

Figure 7 Predicted changes in the population of *A. matthaii* at a level to sustain stock abundance (15% total mortality in the target size).

Ideally, catch records should be available indicating what this level of collection is in terms of colonies collected annually and as a proportion of the local population. Rough estimates of this collection level can be determined by interviewing the area's local collectors and the exporters in the capital.

With resurveys, more data on the vital statistics of coral population being exploited should become available. Growth (including shrinkage and non-growth) mortality and recruitment rates will be more refined. The predicted changes in the population can also be verified during these resurveys.

Similar to the situation in the fish surveys, size class data and therefore matrix and transition models can only be generated from several species of corals out of a long list. We recommend using matrix models for species with good data (range of size class from recruits to adults and ideally at least 100 data recorded). Ideally, matrix models should be done at the minimum for slow and fast-growing species and these numbers applied to other species with similar ecologies and growth rates.

Fisheries-dependent monitoring of species-level catch statistics

As noted, CPUE is an additional tool that can be used to help manage coral collection. This is more critical for coral species or species groups that are not recorded during the fisheries-independent surveys. Fisheries-dependent data include catch statistics recorded by coordinators, on the total number of corals collected, the site of collection, the period of collection (e.g. number of hours) and the rates of wastage. Rates of wastage should also be tracked ideally up to the importer level. The latter information is critical in tracking which corals have low survivorship during transport and therefore should be considered to the list of unsuitable for collection.

Other Relevant Research Issues

For long-term management strategies, the collection of key ecological data that are species-specific is important. For corals, there is a need to collect area-specific data on growth rates and mortality rates through tagging of targeted ornamental species. For fish, there is a need to collect growth rates using age-based techniques. Since fish age-based fisheries assessment techniques are relatively expensive, such studies should prioritize highly collected species (e.g. the butterflyfish *C. rostratus*, the clownfishes *P. biaculeatus* and *A. ocellaris*, and the mandarinfish *S. splendidus*). For both fish and corals, there is also a need to collect information on size-at-first reproduction to help develop size limits to prevent growth overfishing.

Conclusion .... chapter 5

Most countries with a marine ornamental industry do not have a national plan or framework for its management. The certification program under the Marine Aquarium Council facilitates the local management of ornamental fisheries. A critical aspect of the certification program is the formulation of the Collection Area Management Plan. This management plan requires the establishment of no-take marine protected areas and the setting-up of total allowable catch for currently collected species and those that have potential for the trade. Setting reference points such as collection limits is just one of the management strategies being developed by Reef Check for the certification program under the Marine Aquarium Council. Other activities include the establishment of no-take marine protected areas.

Determining reference points entails the use of traditional fisheries models that have been originally developed for slow-growing temperate species. Most of these models are data intensive and have been facilitated through long-term data collection in the fisheries of developed countries. Most developing countries don't have the means for such expensive research programs. Fisheries in the latter countries are also multispecies in nature and landings are typically diffuse and difficult to track. Therefore, these models have limited applications to the fisheries situations in developing countries. There is a general consensus that under these data-less fisheries, ecosystem management approach such as the establishment of no-take zones, seasonal fishing and size limits may be more appropriate. However, application of seasonal and size limits requires a high degree of government involvement that is impractical in developing countries.

The establishment of total no-take zones has particularly become popular and important since they also preserve the habitats and the multispecies ecological relationships in a collection area. There are indications that total no-take zones can accomplish what they were established to do. However, the establishment of no-take zones usually takes several years given the need to consult various stakeholders and ensure meaningful buy-in for their long-term sustainability. Therefore, using output controls such as total allowable catch is also deemed an important management tool.

Under the MAC program, output controls may be easier to enforce because demand can be regulated through the order system. The input control is probably more challenging because of internal (by non-MAC certified local collectors) and external poaching. In addition, the phenomenon of roving collection seems to be prevalent wherein fishermen collect outside their municipal waters. In most areas, collection sites are often remote so poaching cannot be monitored. This also makes the rotation of collection sites inapplicable as a management strategy due to their remoteness from monitoring.

Output control means determining reference points usually derived from traditional fisheries models. Obviously, these models have to be modified, verified and their results reset in an adaptive approach to management. Based on the review of fisheries models, the yield-per-recruit analysis and recent catch records have some application in the ornamental trade. The use of natural mortality rates as F_{MSY} can be a verification tool to this approach or as a separate tool when catch records are not available. Some rough generalizations can be made about the relationship of M and F_{MSY} and it is important that these be verified in the aquarium trade situation. Furthermore, size limits should be set because they have biological and trade bases for non-collection and avoiding wastage. Another output control is the development of a species list that prevents unnecessary collection of organisms from coral reefs that will certainly die in captivity due to some specific ecological requirements.

Equally challenging is the determination of the total allowable catch for corals. For some countries such as Indonesia, there is active collection and international export of corals. There are catch limits but these approaches have not taken into account specific collection area size-class distribution and growth and mortality parameters. We have put forward a general model and theoretical approach in setting total allowable catch for corals. Obviously, this model will be more refined especially with more empirical and species-specific data available for some parameters.

Summary

The aquarium trade is a rapidly expanding industry and there is a threat of overcollecting target species especially since most of these organisms come from the wild. Many of the target organisms are also particularly vulnerable to overharvesting since they possess complex life history characteristics, limited and highly specific habitat requirements and high economic value when traded live. The establishment of marine protected areas, preferably as total no-take zones, is an important strategy in the management of the aquarium trade. It is also important to set sustainable collection limits. Traditionally, total allowable catch (TACs) limits have been based on fisheries models. However, these traditional fisheries models are highly data intensive. Therefore, traditional fisheries models have to be modified in these situations by adding general rules-of-thumb and empirical approach. We have put forward methods for managing the aquarium trade and we envision more refinements as more empirically-derived data become available.

Bibliography............................

Ang PO Jr. and De Wreede RE. 1990 Matrix models for algal life history stages. Mar. Ecol. Prog. Ser. 59: 171-181

Beddington J and Cooke JG. 1983. The potential yield of fish stocks. FAO Fish. Tech. Pap. 242, 47.

Beverton RJH and Holt SJ. 1957. On the dynamics of exploited fish populations. Fish. Invest. Ministr. Agric. Fish. Food (Great Britain) Ser. II 19, 533.

Bruckner AW. 2002. Proceedings of the International Workshop on the Trade of Stony Corals: Development of Sustainable Management Guidelines (April 9-12, 2001, Jakarta, Indonesia). U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service. NOAA Technical Memorandum NMFS-OPR-23, September 2002.

Caddy J. 1998. A short review of precautionary reference points and some proposals for their use in data-poor situations. FAO Fisheries Technical Paper 379.

Caddy JF and Csirke J. 1983. Approximations to sustainable yield for exploited and unexploited stocks. Oceanogr. Trop. 18(1): 3-15

Caswell H. 1990. Matrix population models: construction, analysis and interpretation. Hall Caswell. 2nd edition.

Chiappone M and Sullivan KM. 1996. Distribution, abundance and species composition of juvenile scleractinian corals in the Florida reef tract. Bull. Mar. Sci. 58(2): 555-569

Cole F, Koenig C, Eklund A and Grimes C. 1999. Management and conservation of temperate reef fishes in the grouper-snapper complex of the southeastern United States. American Fisheries Society Symposium 23:233-242

Deriso RB. 1982. Relationship of fishing mortality to natural mortality and growth at the level of maximum sustainable yield. Can. J. Fish. Aquat. Sci. 39: 1054-1058

Doherty PJ. 2002. Variable replenishment and the dynamics of reef fish populations. In P. Sale (ed.) Coral reef fishes: dynamics and diversity in a complex ecosystem. 327-358

Done, T.J. 1987. Simulation of the effects of *Acanthaster planci* on the population structure of massive corals in the genus *Porites*: evidence of population resilience? Coral Reefs 6: 75-90

Done, T.J. 1988. Simulations of the recovery of pre-disturbance size structure in populations of *Porites* spp. damaged by crown-of-thorns starfish. Mar. Biol. 100: 51-61

Edmunds PJ. 2000. Patterns in the distribution of juvenile corals and coral reef community structure in St. John, US Virgin Islands. Mar. Ecol. Prog. Ser. 202: 113-124

Francis RC. 1974. Relationship of fishing mortality to natural mortality at the level of maximum yield under the logistic stock production model. J. Fish. Res. Board Can. 31:1539-1542

Froese R and Pauly D. 2000. FishBase 2000: concepts, design and data sources. *ICLARM Contribution*, 1594. ICLARM: Los Baños, Laguna, Philippines. ISBN 971-8709-99-1. XVII, 344 pp

Gayanilo FC, Sparre P and Pauly D. 2002. FAO-ICLARM Fish Stock Assessment Tools. Food and Agriculture Organization of the United Nations, Rome.

Gomez E, Alcala A, Yap H, Alcala L and Alino P. 1985. Growth studies of commercially important scleractinians. Proceedings of the 5th International Coral Reef Congress 6: 199-204

Harriott VJ. 2003. Can corals be harvested sustainably? Ambio 32 (2): 130-133

Hilborn R and Walters C. 1992. Quantitative fisheries stock assessment: choice, dynamics and uncertainty. Chapman and Hall, New York.

Hughes T. 1984. Population dynamics based on individual size rather than age: a general model with a reef coral example. American Naturalist 123:778-795

Hughes T. 1990. Recruitment limitation, mortality and population regulation in open systems: a case study. Ecology 71 (1): 12-20

Johannes RE. 1998. The case for data-less marine resource management: examples from tropical nearshore finfisheries. TREE 13(6): 243-246

Jones GP, Milicich MI, Emslie MJ and Lunow C. 1999. Self-recruitment in a coral reef fish population. Nature (London) 402: 802-804

Nievales F. 1993. Characterization of some population biology parameters of the reef coral *Pocillopora damicornis* (Linnaeus) in Taklong Island, Guimaras. Master's Thesis. Marine Science Institute-University of the Philippines Diliman.

Patterson K. 1992. Fisheries for small pelagic species: an empirical approach to management targets. Rev. Fish. Biol. Fish. 2:321-338

Ross M. 1984. A quantitative study of the stony coral fishery in Cebu, Philippines. P.S.Z. N.I. Mar. Ecol. 5:75-91

Sadovy Y and Vincent A. 2002. Ecological issues and the trades in live reef fishes. In P. Sale (ed.) Coral reef fishes: dynamics and diversity in a complex ecosystem. 391-420

Swearer SE, Caselle JE, Lea DW and Warner RR. 1999. Larval retention and recruitment in an island population of a coral-reef fish. Nature (London) 402: 799-802

Appendices ....

Appendix 1. Fisheries Models and their Applicability to the Ornamental Trade

There is a significant literature in fisheries management and the models developed to derive reference points (e.g. Hilborn and Walters 1992). One of the earliest models is the concept of sustainable catch as 50% of virgin stock populations. However, there are few unexploited coral reefs to derive such reference points.

Surplus production models are used to determine what fishing pressure is offset by population growth. This is the maximum sustainable yield (MSY) and used to be the 'holy grail' in fisheries science. Operationally, this involves long-term time-series data on catch and effort. The assumptions of these models include logistic population growth. The maximum biomass of the population is the carrying capacity of the environment. Populations in the wild, however, fluctuate wildly so this is easier to assume in theory than in practice. These models also assume density-dependent processes whereas population fluctuations may be driven by changing levels of recruitment (reviewed in Doherty 2002). The other disadvantage of surplus production models is that they ignore age structure and other demographic parameters.

Catch data are critical in determining surplus production. In reality, catch rates change as the fisheries mature due to increasing efficiency. Sadovy and Vincent (2002) also argued that surplus production models are inapplicable for the aquarium trade because of low opportunity and investments costs and the inherent characteristic of the trade that puts high premium (and price) on rare species. The latter argument implies that decline in abundance will still be profitable due to increasing price with rarity and low operation costs.

Like the derivation of MSY, the latest fisheries models require a level of data that is not usually available in the aquarium fishery. With good data on the present and past status of the targeted stocks, Virtual Population Analysis (VPA) can project what is the population's sustainable catch limits. VPA uses the current cohort size and works backwards. However, the analysis requires data on population sizes, and annual natural and fishing mortality rates.

The analysis of the spawning stock biomass per recruit (SPR) ratios is an important tool to determine recruitment overfishing. Basically, the analysis can infer how much spawning biomass is needed for populations to persist. However, the analysis requires data on fecundity, stock-recruitment relationships, age-at-first maturity, and mortality rates. In addition, this model has been postulated to be inapplicable especially to hermaphroditic reef fishes (Cole et al. 1999).

Sustainable exploitation of fisheries needs to balance reproduction, body growth, fishing mortality and natural mortality. Yield-per-recruit (YPR) models, in a way, are superior to surplus production models because they separate these components in stock assessment analyses. Yield-per-recruit models approximate what fishing mortality is sustainable given population growth parameters and mortality rates that are inferred from age structure data and length-at-first capture data.

The fundamental yield-per-recruit model assumes a steady state, i.e. that recruitment is constant, and hence the age structure of the population is the same if we followed a single cohort through time. Hence, yield is measured 'per recruit' (Beverton and Holt 1957). There is evidence that age structure is far from constant in reef fish populations (reviewed in Doherty 2002).

Because of equilibrium assumptions, yield-per-recruit analyses only predict long-term effects. For example, a decrease in fishing effort as shown to be optimal in this analysis does not immediately translate to increased catch. The duration of the predictions also depend upon the longevity of the fish species and length of its exploitation. The duration of the transition period can be several years for fish of high longevity and shorter for short-lived fish. For very short-lived fish, the distinction between short- and long-term effects does not even apply because the stock is never at equilibrium (Froese and Pauly 2000). The distinction between short-lived and long-lived species has not been clearly defined.

Estimates of natural mortality rates are necessary in yield-per-recruit analyses. Pauly's empirical equation is commonly used in estimating natural mortality rates. Estimates using this approach, however, do not have confidence intervals making yield-per-recruit estimates less reliable. The potential effect of fishing mortality on the spawners and on future recruitment is also ignored in yield-per-recruit analyses. This is critical since there is evidence of population self-recruitment in reef fish populations (Swearer et al. 1999 Jones et al. 1999). Overfishing of spawning adults may mean lower recruitment in the future.

The relationship between Natural Mortality (M) and F_{MSY}

Caddy and Csirke (1983) presented data on the relationships between M and F_{MSY}. Their data indicated that F_{MSY} ranges from a third to five times the value of M and they suggest that $M = F_{MSY}$ is not a common situation. These wide-ranging estimates also suggest that there is a need to accumulate empirical information on the relationship between reference points such as F_{MSY} and biological criteria such as M. However, Patterson (1992) has showed some useful generalizations that are relevant to high mortality tropical species. He examined a large number of stocks of small pelagic fish with high natural mortality rates. He showed that mean exploitation rates over 0.4 ($F = 2/3\ M$) consistently caused stocks to decline, while exploitation ratios below 0.33 ($F = ½\ M$) have generally allowed stocks to increase in size. (This is another reference point for the yield-per-recruit analyses.) Several researchers have also agreed that F_{MSY} is larger than M (Francis 1974, Deriso 1982 and Beddington and Cooke 1983). This is certainly the case for those fisheries where recruitment is largely independent of stock size (e.g. coral reef fishes) and where most of the landings are from the previous year's recruits.

Determining Catch Limits for Ornamental Corals

The international trade in corals is regulated under the Convention on the International Trade in Endangered Species of Wild Flora and Fauna (CITES) agreement. The requirements under the CITES agreement include the provision that the exports are identified to the species level but this is impractical due to the recognized complexities of coral identification. The provision also includes that collection will not be detrimental to the species. One approach to meeting the "no-detriment" requirement of CITES is to set export quotas for a trade country. This has presented complications for Indonesia, where quotas are largely based on existing practices without adequate scientific evidence for ecological sustainability. The major coral taxa collected in the ornamental trade are the colorful, large-polyped species such as *Euphyllia* spp., *Goniopora* spp., *Catalaphyllia jardinei,* and *Trachyphyllia geoffroyi*. There is also little ecological information available on many of these species to provide a basis for sustainable collection limits.

The use of models that predict population changes is an attractive tool for coral 'fisheries' management. For instance, matrix models have been used in understanding the dynamics of biological systems (Caswell 1990). Transition matrices have been used to predict changes in the population dynamics of invertebrates and vertebrates. These matrix models variously use age-, size- and stage-classified data and transition matrices to predict long-term population changes. The projected population changes using these models have been corroborated in the observations of organisms such as the corals *Agaricia agaricites* (Hughes 1984), and *Porites* spp. (Done 1987, 1988), the bryozoan *Cellepora pumicosa* (Hughes 1990) and a brown alga (Ang and De Wreede 1990). Hughes (1984) showed that a size-classified matrix model from field data and a transition matrix that incorporates vital processes such as mortality, growth and recruitment could be functional tools in measuring and predicting coral population density under non-perturbed or perturbed (e.g. severe storm) conditions at time scales that are otherwise impossible to measure at the time of study. Done (1987, 1988) also used a similar population model to evaluate the damage of the crown-of-thorn starfish *Acanthaster planci* outbreaks on *Porites* populations.

There is little available empirical information on population vital statistics of corals and especially those species under ornamental exploitation (Harriott 2003). Nievales (1993), in an unpublished thesis, empirically determined growth, reproduction, recruitment and mortality rates of *Pocillopora damicornis*. She used these vital statistics to construct a size-classified transition matrix in predicting the population size and structure of *P. damicornis* for the next twenty-five years under different scenarios. This coral species is collected for the ornamental trade and its vital statistics can be used as a starting point in modeling the effects of collection on other species until information are available for these corals.

The monitoring sub-group in the "Proceedings of the International Workshop on the Trade in Stony Corals: Development of Sustainable Management Guidelines (April 9 to 12, 2001 in Jakarta, Indonesia)" (Bruckner 2002) formulated the following guidelines concerning quotas:

1.) Quotas are meant to be conservative;
2.) Quotas are ideally set for particular species;
3.) Any type of disturbance (e.g. bleaching) should trigger a new stock assessment that will modify quotas if appropriate;
4.) Quotas are set for whole colony collection not just the removal of fragments; and
5.) There is a need to track wastage and rejections as well since these affect estimates of current collection levels.

Setting 'sustainable' collection limits should be only a part of suite of management strategies for coral collection. Sustainable collection also implies protecting sites from the trade through the establishment of no-take zones. This maintains a source of adult corals that can provide larvae for replenishing the area's collection sites. Coral harvesting should also be sited away from recreational areas such as dive sites where a greater economic and social value can be gained through maintaining the quality of the resource.