Diagnosis and Conservation of the Hawksbill Turtle Population in the Cuban Archipelago

T. Doi, R. Marquez, H. Kimoto, and N. Azeno

March 1, 1992

Diagnosis and Conservation of the Hawksbill Turtle Population in the Cuban Archipelago

T. Doi, R. Marquez, H. Kimoto, and N. AZENO

1 Data collectin

2 Population dynamics technique

2.1 Phase 1 - Growth

2.2 Phase 2 - Life cycle

2.3 Phase 3 - Survival rate, availability and population size obtained from catch statistics

2.4 Phase 4 - Is the present status of population under-exploitation or overfishing? [Diagnosis 2]

2.5 Phase 5 - Sustainable yields at various fishing mortarity coefficient under the present conditions of fishing [Diagnosis 3]

2.6 Phase 6 - Optimum status of population in changed condition of fishing [Diagnosis 4]

2.7 Phase 7 - Transient phenomena in future after changing condition of fishing [Future prediction]

3 Result obtained

3.1 Growth

3.2 Natural mortality coefficient

3.3 Biological information of hawksbill sea turtle population in Cuban Archipelago

3.4 Survival rate and availability obtained from catch statistics

3.5 Estimate of population size

3.6 Diagnosis 1

3.7 Diagnosis 2

3.8 Diagnosis 3

3.9 Diagnosis 4

3.10 Verification of the results

Summary

Diagnosis and Conservation of the Hawksbill Turtle Population in the Cuban Archipelago

T. Doi, R. Marquez, H. Kimoto, and N. Azeno

1 Data collection

For the population dynamics, biological and catch information are necessary. From February 28 to March 13, 1991, we went to Cuba to collect data for the population analysis of the hawksbill turtle. Through the cooperation of The Ministry of Fisheries Industry of Cuba, we were able to obtain sufficient data for our research. The collected data are recorded in the Cuba-Japan Cooperative Hawksbill Turtle Population Analysis Project Report.

From June 16 to June 28, 1991, we went to Cuba again. The maturity and hatchability in the preceding collected data were corrected.

2 Population dynamics technique

The concept of resource managed fisheries is the same as the methods practiced by agriculture. Farmers save seeds from the harvest, plant them during the appropriate season, water them for growth, eliminate weeds and insects, spread fertilizer for better harvests, and again save seeds from the harvest for the following year. Fishermen need to follow the example of farmers; they need to endeavour to conserve resources, to maintain an optimum level of population and to protect resources so they are available for mankind forever.

For resource managed fisheries, the first approach is the stock assessment or population dynamics. In population dynamics, the following four basic equations express the principles of the analysis.

Basic equations	Parameters
Growth equation	anabolism, catabolism, food consumption
Survival process	natural mortality, predation, catch
Reproduction mechanism	spawning, hatching, density effect
Catch mechanism	catchability coefficient, fishing effort

The details of the equations and their solution techniques are presented by DOI (1982). It is convenient to use a software program called DOIRAP, which is not fragmental but holistic for the analysis technique. If by only one theory we can solve every problem, we call it a unified field theory, in which individual theories for individual occasions or situations are not taken into account. The DOIRAP system, that is a unified field theory, can be applied to any situations of population problems, to be emphasized at first. The second important consideration is the relationship between each individual job. Considering growth as an example of individual job in the usual method of analysis, to obtain a specific growth law is all that can be achieved. But in the DOIRAP system growth is connected with vital factors such as anabolism, catabolism analysis, natural mortality coefficient, taking mortality coefficient, population size, diagnosis, etc. No job is independent but all jobs are connected with each other. Absurd assumptions or wrong results are rejected by such a connected network.

In DOIRAP system, using the four fundamental equations in fall connection, calculation proceed along the seven phases shown in the below.

2.1 Phase 1 – Growth

Growth law can be obtained from the sets of measurements of length l, weight W and age t in individual animals, as is represented by the following equations in the DOIRAP system.

The differential equations as follows:

$$\frac{dW}{dt} = \alpha W^{2/3} - \beta W \tag{1}$$

$$W = Al^3 \tag{2}$$

where

α: coefficient of anabolism;

β: coefficient of catabolism;

dW: increment of weight in time increment dt;

A: coefficient of fatness.

$$l = a - be^{-kt} = a[1 - e^{-k(t-t_0)}] \tag{3}$$

Constants a and b are calculated from the following difference equations:

$$l_{n+1} = \beta_0 + \beta_1 l_n$$
$$\beta_0 = a(1 - e^{-k\tau}) \tag{4}$$
$$\beta_1 = e^{-k\tau}$$

n: numerical value of τ interval

The above equation is linear regressive. Therefore, we can calculate β_0 and β_1. Then a and k are estimated from β_0 and β_1, where b or t_0 is to be decided from the initial conditions, as follows:

$$k = -\frac{1}{\tau}\log\beta_1$$

$$a=\frac{\beta_0}{1-\beta_1} \tag{5}$$

$$b=\frac{1}{n+1}\sum_{t=c}^{c+n}\frac{a-l}{e^{-k}}$$

$$t_0=\frac{1}{k}\log\frac{b}{a}$$

From a set of observed values of l_i and W_i (i is number of individuals, $i=1, 2, 3\cdots n$, n is the sample size), parameter A can be estimated from the least square method for Eqn. (2) as follows:

$$A=\frac{\sum_{i=1}^{n} W_i l_i^3}{\sum_{i=1}^{n} l_i^6} \tag{6}$$

or for $\log W=\log A+3\log l$

$$\log A=\frac{1}{n}\left[\sum_{i=1}^{n}\log W_i-3\sum_{i=1}^{n}\log l_i\right] \tag{6'}$$

If we obtain the growth parameters a, k and A in Eqn. (1) from a set of observed values (age, W, l), not only coefficients of anabolism and catabolism but also amount of anabolism, and growth per day are calculated from the fundamental growth law of body weight Eqn. (1), as follows:

$$\alpha=3A^{1/3}ak$$

$$\beta=3k$$

$$\text{Amount of anabolism per day} = \frac{\alpha}{365} W^{2/3}$$

$$\text{Amount of catabolism per day} = \frac{\beta}{365} W$$

$$\text{Growth of weight per day} = \frac{\alpha}{365} W^{2/3} - \frac{\beta}{365} W$$

2.2 Phase 2 – Life cycle

Concretely speaking, Phase 2 includes widely biomass analysis estimating of natural mortality coefficient, diagnosis 1 and life cycle analysis. Necessary input data, which are biologically important as well as growth data, are life cycle and reproduction.

Life cycle is the essential concept in studying biology. Basic components of life cycle are life span, age-specific maturity and age-specific fecundity. The components of the life cycle connect with the following procedures of biomass analysis, estimate of natural mortality coefficient and life cycle analysis, as well as diagnosis 1.

(1) Biomass analysis

Biomass in each year or at a given age can be easily calculated under a given annual survival rate, because individual weight is already obtained in the previous section, where

W_x : individual weight at x-age

P_x : biomass at x-age

S : number of population in given n-age after larval stage,

P_x is represented as follows:

$$P_x = NS^{x-n} W_x \tag{7}$$

Now N and S are unknown but the relative pattern of biomass can be calculated in various S and also drawn in a figure. This figure of biomass curves can be also indicated by computer.

(2) Estimate of natural mortality coefficient

There are many methods of estimating natural mortality coefficient, although they are mostly rather difficult to apply. Here we show a slightly rough but simple and rapid method which is derived from the biomass curves shown in a figure.

Generally speaking, biomass increases at the young stage, has a dome at a given age, and decreases to nearly zero at maximum age or life span. From the curves the adequate value of S will be also to choose. The relationship between natural mortality coefficient and survival rate in the underexploited is expressed as

$$S_o = e^{-M}$$

(3) Life cycle analysis

The survival rate during egg to 1-age is much less than in the case of young or adult fishes. In the virgin or underexploited state the population maintains a given level. Therefore, the following equation is established:

$$S' \sum_{x=1}^{20} PS^{x-1} MTR(x) H(x) = 1 \tag{8}$$

where,

S' : Survival rate during egg to 1-age

S : Annual survival rate of 1-age fish to 20-age

P : Sex ratio

$MTR(x)$: Maturity proportion of x-age

$H(x)$: Fecundity of x-age.

When S is estimated in the above paragraph, and P can be observed from biological survey, unknown parameter S' in Eqn. (8) can be solved easily. Accordingly natural mortality coefficient in juvenile stage can be estimated as follows:

$$M' = -\log S'$$

where M' is natural mortality coefficient during egg to 1-age. M' cannot usually be observed by survey. However, by the theoretical process of life cycle we can estimate it deductively.

2.3 Phase 3 – Survival rate, availability and population size obtained from catch statistics

It is natural that catch is important information in analysis fisheries problems. The most essential data for stock assessment are total catch and age composition of catch. In order to obtain age composition, many different studies must be carried out, such as aging character, reading age character, sampling methods from catch, etc. Therefore, sometimes we must use category composition instead of age composition, because categories are surveyed easily in the fish market.

(1) Survival rate and rate of exploitation

It is usual in estimating the survival rate S to use age composition. Although there are several calculation methods, the average age method (DOI, 1948) is recomented.

Age of fish is not as wide as $0-\infty$. Put a for the lowest age and $a+\Delta$ for the highest age, where Δ=(highest age)−(lowest age). The average age $\bar{x}$ of fishes, in a sample which is larger than 50 individuals, is regarded as normal distribution with mean, m, and standard deviation $\frac{\sigma}{\sqrt{n}}$. Here m is:

$$m(a,S,\Delta)=\frac{xS^x}{S^x}=a+K(S,\Delta) \qquad (9)$$

and value of m and σ are indicated in the table (Average age and survival rate), as changes of S and Δ. Accordingly in calculating S by average age method, the following steps are carried out successively:

1. To find a and Δ
2. Calculation of $\bar{x}$
3. To obtain K: $K=\bar{x}-a$
4. To search for S in the table

Corresponding to k and Δ under consideration, numerical interpolation or graphical interpolation may be adopted. The table is of course built in DOIRAP program.

Another common method is linear regressive technique of logarithm of age composition. This regressive methods is also built in DOIRAP.

Fishing mortality coefficient F is defined by:

$$S = e^{-(M+F)} \tag{10}$$

that is:

$$F = -(\log S) - M \tag{11}$$

F is a instantaneous coefficient, which is a little difficult to grasp. Therefore, we usually use rate of exploitation E which is ratio of catch to total population.

$$E = \frac{F}{M+F}(1-S) \tag{12}$$

(2) Availability

In the sea, populations of the younger age are more abundant than those of older ones. But in the actual catches, the number of younger specimens is sometimes not greater than that of the older ones up to a given age (full recruited age). Introducing the availability Q_x (x is age), which is defined by

$$\frac{x\text{-age catchable proportion}}{x\text{-age population in the sea}} = Q_x$$

Q_x is less than 1 up to fully recruited age, and Q_x is equal to 1 in the age beyond fully recruited age. Q_x is determined by mesh size, fishing area, fishing season, etc., which are conditions relevant to human activity of fishing operations. Q_x can be calculated from are compositions.

If we know the age composition of catch $C(x)$, natural mortality coefficient M and fishing mortality coefficient F, availability Q_x is calculated as follows:

Denoting r is fully recruited age,

$Q_x = 1$ at $x \geqq r$

$Q_x < 1$ at $x < r-1$

The general formula for estimating Q_x is derived from the equation below.

$$\frac{C(x)}{Q_x} = C(x-1)\left[\frac{1-Q_{x-1}}{Q_{x-1}} e^{-M} + e^{-(M+F)}\right] \quad (13)$$

If we put $x=r$ in Eqn. (13), Q_{r-1} can be easily calculated. And then Q_x can be successively calculated back to age x less than r.

(3) Population size

The last job to remain in phase 3 of the DOIRAP is to estimate population size. The rate of exploitation E has already been estimated and total catch Y is known as input data. Therefore, the catchable population size P_c is easily calculated as follows:

$$P_c = \frac{Y}{E}$$

Number of population by age os necessary in the following diagnosis analysis. Calculation is carried out by the following procedures. Denoting N as the number of 1-age fishes in the sea, the number of fishes by age in the sea, abundance of adults and weight of fishes by age in the catchable phase are represented in Appendix 1.

$W(x)$ are already known in growth analysis and both survival rate of virgin stock S_0 and the present survival rate S are already estimated, too. The population size P_c estimated above is the total of the right hand column of the above representation (Table ??). In this equation the unknown parameter is only N. Therefore, N can be simply obtained. Then we can calculate the above representation of both number in the sea and weight in the catchable phase.

(4) Diagnosis 1 ----- size limitation or legal size

It is not rational to catch too small or juvenile fishes, because it decreases not only the future abundance but also destroys the normal reproduction mechanism.

Size limit can be found from the biomass analysis. The biomass curve has a dome at a certain age. We choose the adequate curve from several trials of various values of S. On the chosen or adopted curve, we know the age at which the biomass has a dome. Up to this age fishing should be prohibited, because the biomass steadily increases year by year. Above this age, biomass decrease gradually year by year even if there is no catch. Accordingly fish beyond this age can be caught. Therefore, it is recommendable not to take fishes below this age. The size limit or legal size is obtained from the growth law. If, in the actual fisheries, a lot of fishes small then size limitation will be caught, it is one reason of overfishing.

2.4 Phase 4 – Is the present status of population under-exploitation or overfishing? [Diagnosis 2]

The criterion to judge underexploitation or overfishing is the reproduction, that is the total number of adults or eggs spawned by adults. If this amount becomes less than half of that of the virgin stock, we can judge that the present status is overfishing. The reason why such a very practical one under the lack of reproduction mechanism.

Actual calculation can be carried out from weight, natural mortality coefficient, fishing mortality coefficient, availability, fecundity, maturity percentage which are the important biological parameters of life cycle.

The number of fishes at the age of 1 year can be estimated as explained in the previous section. Then, by using the estimated values of natural mortality coefficient, fishing mortality coefficient, availability, weight, fecundity, maturity, etc., the numbers of each age-group in the sea N, catchable population number N_c, catchable biomass P_c, expected catch C, expected yield Y, total number of adults A, total number of eggs spawned EGG are all reconstructed.
In the above calculation, the point to be careful is the following procedure:

$$N_{x+1} = Q_x N_x e^{-M} + (1-Q_x) N_x e^{-(M+F)} \tag{14}$$

The same calculation can be carried out as for the virgin stock in which fishing mortality coefficient $F=0$. The number of age 1 fishes in the sea can be adopted the same values in the present status, although it is a little doubtful theoretically.

After both calculations we can compare the present status with the virgin stock. Then the rate of decrease can be calculated for not only population size but also reproduction.

2.5 Phase 5 – Sustainable yields at various fishing mortality coefficient under the present conditions of fishing [Diagnosis 3]

After judging the present status population to be overfishing or underexploitation by Diagnosis 2, we must then proceed not only to calculate sustainable yields but also to estimate what level of exploitation is the optimum which provides a maximum sustainable yield under the present conditions of fishing.

Because of the density-dependent effect, relationship or reproduction curve between abundance of adults and recruitment is not linear but convex against the axis of abundance of adults. Such a reproduction is written as follows:

$$R=K(A)A \tag{15}$$

where,

R: recruitment

A: abundance of adults

$K(A)$: rate of reproduction

$K(A)$ is not a constant but a function of A

Figure ?? indicates types of reproduction curves (R-A curves) and $K(A)$ curves. Usually, as for reproduction curve, saturation type and domed type are used. However simplified type is also adopted frequently, because of lack of information about reproduction.

In order to estimate a sustainable yield, it is necessary to know equilibilium condition. We can obtain it by the following procedure.

$$N_1 = R$$

$$N(i+1) = [Q_i S + (1-Q_i) S_0] N(i) = b_{i+1} N_i$$

$$= b_{i+1} U_i N_1 = U_{i+1} N_1 = U_{i+1} R$$

$$A = \sum_{i=1}^{\lambda} N_i MTR(i) = R \sum_{i=1}^{\lambda} U_i MTR(i) \qquad (16)$$

Therefore, the following equilibilium condition from Eqns. (15) and (16).

$$\frac{1}{K(A)} = \sum_{i=1}^{\lambda} U_i MTR(i) \qquad (17)$$

Value of right-hand term is calculated easily when we know M, Q_i, F, $MTR(i)$. Accordingly we can obtain the values of A. Successively it is possible to get corresponding values of R.

Thus A and F are estimated purely in the equilibrium state. The corresponding sustainable yield Y, as well as N, N_c, P_c, C, are calculated by the same process explained in the Diagnosis 2.

When we plot values of Y against A, this figure is sustainable yield curve which has a dome in the middle part of A and has zero at the both sides ($A=0$ and $A=$virgin value). Needless to say, the state of dome is the maximum sustainable yield. This state is the optimum level under the present conditions of fishing. If it is found to be underexploited or overfishing, we endeavour to approach to the optimum level by adequate measure of fisheries regulation.

2.6 Phase 6 – Optimum status of population in changed condition of fishing [Diagnosis 4]

Condition of fishing means type of gear, mesh size, size limitation, effort regulations, etc.. Assuming we can change fishing conditions in future, what is the best fishery under which the optimum level of population can be maintained? This is the problem of Diagnosis 4 that is the calculation of phase 6.

According to changes in fishing conditions, values of availability Q change. Therefore many calculations for Diagnosis 4 must be carried out for various combinations of Q and F. Calculations themselves are quite the same as those of Diagnosis 3 indicated isopleth diagnosis of total yield Y and counter line of rate of decrease of reproduction, which was presented by DOI(1973). In Fig. ?? abscissa is fishing mortality coefficient F and ordinate shows corresponding values of Q by age

2.7 Phase 7 – Transient phenomena in future after changing

conditions of fishing [Future prediction]

Just after we adopt a new regulation, population changes transiently and converse to a new equilibilium level. This calculation will be carried out by forward cohort analysis which is built in DOIRAP soft as DOIPOP.

3 Results obtained

3.1 Growth

Growth is one of the basic biological characteristics, and it is usually easy to observe or measure. For the hawksbill sea turtle, *Eretmochelys imbricata*, it is difficult to obtain growth parameters not only because no aging character exists but also because the hawksbill sea turtle has a long life span. However, we obtained growth parameters of the hawksbill sea turtle by using previously reported and collected information as in Section 2.1.

Growth equation of the hawksbill sea turtle in the Cuban Archipelago is as follows;

$$L = 100 - 91.82\, e^{-0.101t}$$

L : carapace length (cm)
t : age

The relation between carapace length and body weight has been calculated as follows;

$$W = 0.000129\, L^3$$

W : body weight (kg)
L : carapace length (cm)

Accordingly, we calculated the carapace length and the weight at age of Hawksbill Turtle. The result obtained indicate Table 3-1.

3.2 Natural mortality coefficient

Here we are using the method of biomass analysis to estimate the natural mortality coefficient *M*. Using one year of age after the larval stage as a standard age, the relative population number and relative biomass by age are calculated for various values (from 0.1 to 0.9) of survival rate(S). From these results, We decided the natural survival rate as described Fig 3-1.

According to the present fishing information, some turtle, which are near 100cm in carapace length, were appeared. So the biomass at maximum age must be remained in virgin stock.

For an example in Fig. 3-1, the curve of $S=0.9$ seems to be adequate.

Here, we decide that the natural survival rate S is 0.9.

Then, the natural mortality coefficient (M/year) of the hawksbill sea turtle in the Cuban Archipelago is as follows;

$$M=-\log S=-\log 0.9=0.1054$$

3.3 Biological information of hawksbill sea turtle population in Cuban Archipelago

Biological information of hawksbill sea turtle in the Cuban Archipelago is summarized in Table 3-2. Biological information consists of life span, natural mortality coefficient, maturation rate, sex ratio, fecundity and fertility.

Fertility shows the effective number of spawned eggs, and is decided by the fecundity per one nesting (130), the number of spawning times (2.3 times per year), breeding cycle(2.6 years), and hatchability(0.75).

3.4 Survival rate and availability obtained from catch statistics

The age composition of catch of hawksbill sea turtle in the Cuban Archipelago is shown in Table 3-3.

It is usual in estimating the present survival rate S to use age composition. Although there are several calculation methods, we calculated survival rate using the average age method. Calculated results of the present survival rate S is as follows;

Present survival rate $S=0.7820$

Fishing mortality coefficient $F=-\log(0.7820)-0.1054$

$$=0.1405$$

Rate of exploitation $E=0.1246$

We decided fully recruited age of hawksbill sea turtle is 10 in Table 3-3. The availability Q_x (x is age) can be calculated as shown in Table 3-2

3.5 Estimate of population size

The rate of exploitation E has already been estimated and total catch is known as follows;

$E=0.1246$

Total catch = 246 tons

therefore,the catchable population size P is calculated as follows;

$$P=\frac{Y}{E}=\frac{246}{0.1246}=1974 \quad (tons)$$

P(shown in 2-3-2) is represented as follows;

$$P=N_1Q_1W(1)+N_1[Q_1S+(1-Q_1)S_0]Q_2W(2)+N_1[Q_1S+(1-Q_1)S_0][Q_2S+(1-Q_2)S_0]Q_3W(3)+ \cdots + N_1\prod_{x=2}^{\lambda-1}[Q_xS+(1-Q_x)S_0]Q_\lambda W(\lambda)$$

On the basis of obtained W(x), both survival rates S_0 (=0.9) in virgin stock and S(=0.782) in present one, availability by age can be calculated, N_1 is obtained as follows;

$N_1 = 1.99\times10^4$ individuals

Then we can calculate population number, biomass in the sea and in the catchable phase, adult stock(male and female) in number and weight, and eggs spawned. The eggs are the product of adult stock number multiplied by sex ratio,maturation rate, and fertility.
Calculated results shown in Table 3-4.

(1) Population in the sea

Population number over one year of age is 14.6×10^4 turtles; and biomass, 2800 tons.

(2) Population in the catchable phase

Population number in the catchable phase over 50cm(carapace length) is 4.5×10^4 turtles; and biomass, 1950 tons.

(3) Rate of exploitation

Present rate of exploitation $=0.125$

Natural mortality coefficient $=0.105$

(4) Present status of the population

The present adult stock and total eggs spawned decreased to about 40% of virgin stock as follows;

The adult stock($\times10^4$): The present stock/The virgin stock

$=2.4/6.2=0.39$

The total eggs($\times10^4$): The present stock/The virgin stock

$=166/429=0.39$

3.6 Diagnosis 1

It is not rational to catch too small for the hawksbill sea turtle. In the biomass curve of the hawksbill sea turtle as shown in Fig 3-1, the adequate curve adopted is the curve of S=0.9 which has a dome in age 12. It is recommendable not take turtles below this age. From the growth rate of the hawksbill sea turtle and effective utilization of natural resources, the optimum carapace length at first capture should be 70 cm (12 years). The present carapace length, however, is 50 cm(7years). It is not good for conservation of population of the hawksbill sea turtle.

3.7 Diagnosis 2

Diagnosis 2 judges the status of a population whether it is overfished, optimum level, or under exploited, as explained in Chap. 2.3.

The criterion of diagnosis is the rate of decrease of adults or total eggs spawned. From the average sustainable yield curve, it was found that a 50% level of virgin stock is an optimum level to obtain a very good sustainable yield. The present adult stock and total eggs spawned decrease to 40% of virgin stock. Accordingly, the present status is not concluded to be overfished, but regarded to be at warning level. However, it is surely expressed that this level does not exceed below the threshold.

3.8 Diagnosis 3

Here, we estimate what level of exploitation is the optimum in present fisheries condition (carapace length at first capture is 50cm). For this purpose, we calculated total catch (C in number and Y in weight), adult stock (number and weight), reproduction rate K, maximum sustainable yield and efficiency of fishing Y/F in Table 3-5.

The reproduction curve of the hawksbill turtle in the Cuban Archipelago is unknown. So in this calculation we used the simplified reproduction curve (type V) which is composed of two straight lines as shown in Fig.3-2.

The maximum sustainable yield thus calculated is as follows;

Catch in number C: 5500 individuals

Yield Y : 245 tons

Fishing mortality coefficient F (per year) : 0.141

It is nearly the present status of fishing. The value of fishing mortality coefficient F is near 0.1, which is indicated at 50% decrease rate of adults of virgin stock. In this state, the sustainable yield is 220 ton less than the present level. It is caused by using the simplified reproduction curve like Type V.

If we use domed reproduction curve like Type III or Type IV, the sustainable yield at the 50% is expected to be more than 245 ton (that is the maximum sustainable yield on present level).

3.9 Diagnosis 4

In this phase, we evaluate what level of exploitation is the optimum under conditions of change on fishing method. A change of fisheries condition means a change of availability. We can get the optimum fisheries condition and optimum fishing mortality coefficient F for better maximum sustainable yield levels under the new fisheries regulations. Here, we calculated sustainable yields when fisheries condition are changed by regulating the carapace length and mesh size as shown in Table 3-6. When, as a new regulation, we regulate fisheries by a desirable size limitation of 70cm carapace length, it is possible calculate the year-by-year changes of population, catch and age composition for a long-term period after implementation of new regulation as shown in Table 3-7(1)-(3) for fisheries mortality coefficient $F=0.141$ (present), 0.2 and 0.3.

3.9.1 Diagnosis 4-1, Sustainable yield when carapace length at first capture is 70cm under the present rate of exploitation

By adopting measures to limit the carapace length of catch to over 70cm(12 years), although catch will decrease at first, it will increase year by year. Ten years after stock number, catch in number etc. will change as follows; The biomass will increase by 30%, and large-sized turtles will be available under the present rate of exploitation. Catch in number is expected to decrease by 40% (3500 individuals), and catch in weight is expected to decrease by 10% (218 tons).

3.9.2 Diagnosis 4-2, Sustainable yield when carapace length at first capture is 70cm under fishing mortality coefficient is 0.2

Sufficient number of adult stock can be maintained by adopting measures to limit the carapace length of catch to over 70cm (12years). Thus, we can increase the fishing mortality coefficient. When the fishing mortality coefficient is 0.2, the biomass will increase by 15%, and large-sized turtles will be available after 10 years. The population will increase to a level which provides sustainable yield with a 25% decreased catch in number (4100 individuals) and catch in weight is 249 tons that is a little more than present level.

3.9.3 Diagnosis 4-3, Sustainable yield when carapace length at first capture is 70cm under fishing mortality coefficient is 0.3

When the fishing mortality coefficient is 0.3, *i.e.* two times the present coefficient, the biomass will increase a little more than present level, and large-sized turtles will be available. The population will increase to a level which provides sustainable yield with a 15% decreased catch in number (4800 individuals) and a little more than 10% increased catch in weight (274 tons).

3.10 Verification of the results

3.10.1 Aim

The diagnosis of hawksbill turtle stock was concluded from the holistically from biological data and catch statistics, using a mathematical model on living population as one of the laws of nature science It must be verified whether the results are correct and comparable to actual phenomena. If there are deficiencies, inferorities or insufficiencies found in verification process, they must be reconsidered as feedback for future researches. Usually, as for marine living things, verification are difficult problems due to their long-term scale of breeding and growth.

However, as for hawksbill turtle, information nests and eggs are available to verify the calculated results, because spawning and eggs of mature females can be easily observed on sandy nesting beaches.

Calculated results on spawning are as follows;

Total eggs	1658 (in thousand)
Total adult animals	24.0 (in thousand)
Total adult females	19.2 (in thousand)
Total landed adult females	7.4 (in thousand)
Survival rate during hatchling	0.0120/year

Although observing landed adults, nests and eggs will be a difficult problem in itself, we should carried out beach surveys in order to verify the calculated results.

3.10.2 features of coastal line

The Cuban Archipelago is dotted with many unfrequented sandy beaches and many small uninhabited islands. The following length of coastal lines are already listed;

Total coastal line length	5746 km
Total sandy beach length	1159 km
Length of sandy beach adapted to build nest, N	345 km

Such listing is important for sampling surveys. Nesting beaches, whose total length is 345 km, should be marked on the map of the Archipelago.

3.10.3 Application of sampling method

Needless to say, a complete counting of nests and eggs along the total nest beaches in every month is impossible. Thus a sample survey method is to be introduced. In accordance with the sample survey method, we have to select nest beaches (total length:n km) from the nest beaches (N km) as samples. Thus sampling ratio is;

$$\text{Sampling ratio } (r) = \frac{\text{Sample beach } (n)}{\text{Nest beach } (N)}$$

Beach surveys will be carried out in the sampled beach, and nests and eggs shall be able to be observed. Putting X and Y as eggs and nests observed, total number of eggs and nests all around The Archipelago can be estimated by the following equations;

$$\text{Total eggs } HH = \frac{X}{r}$$

$$\text{Total nests } JJ = \frac{Y}{r}$$

The number of beaches to be sampled is decided in advance before conducting surveys. According to the sampling theory, the precision ε or coefficient of variance CV can be expressed as follows;

$$\varepsilon = CV = \frac{\sigma}{m}\sqrt{\frac{N-n}{n(N-1)}}$$

where,

m: average eggs or nest per unit length (1 km, for instance)

σ: standard deviation of eggs or nests per unit length

Assuming m and σ in advance before survey, number of sampled beaches n can be calculated to a given aimed precision we want. After the surveys, achieved precision can be recalculated from the actually observed values of m and σ.

Sometimes, in order to improve a precision and efficiency of survey, stratified sampling method or cluster sampling method will be adopted instead of simple sampling method above-explained.

3.10.4 Trial calculation

Following data were obtained, we can estimate total eggs of hawksbill sea turtle in the Cuban Archipelago.

As above-described;

Total coastline length in the Cuban Archipelago 5746km

total sandy beach 1159km

nest beach length 345km

fecundity per one nesting 130

hatchability 0.75

In trial, number of nest is 3 per 18km per day from the Cuban beach survey. Assuming that the turtles are nesting throughout the year, we can obtain as follows;

total number of nest $=3\times(345/18)\times 365=21000$

Thus, the total eggs HH can be estimated as follows;

$HH=21000\times 130=2730000$

Effective eggs after hatching $=205\times 10^4$.

On the other hand, by using DOIRAP system, effective eggs was obtained as 166×10^4, and it is near to the above result. From this, it seems that the population analysis result is proper.

Diagnosis and Conservation of the Hawksbill Turtle Population in the Cuban Archipelago

T. Doi, R. Marquez, H. Kimoto, and N. Azeno

(Summary)

1 Data collection

From February 28 to March 13, 1991, we went to Cuba to collect data for the population analysis of the hawksbill turtle. Through the cooperation of the Ministry of Fisheries Industry of Cuba, we were able to obtain sufficient data for our research. The collected data are recorded in the Cuba-Japan Cooperative Hawksbill Turtle Population Analysis Project Report.

From June 16 to June 28, 1991, we went to Cuba again. The maturity and the hatchability in the preceding collected data were corrected.

2 Population dynamics technique

The laws of population dynamics can be represented by the growth equation, survival process, reproduction mechanism, and the catch equation. The analysis techniques are given by the holistic unified field theory called DOIRAP.

3 Calculated results

The calculated results of the DOIRAP analysis using the collected data are summarized as follows:

1) Optimum age at first capture from the standpoint of resource managed fisheries [Diagnosis 1]

From the growth rate of the hawksbill turtle and effective utilization ofnatural resources, the optimum carapace length at first capture should be 70cm (12 years). The present carapace length, however, is 50cm (7 years).

2) Population in the sea

Population number over one year of age is 146000 turtles; and biomass, 2800 tons.

3) Population in the catchable phase

Population number in the catchable phase over 50cm (carapace length) is 45000 turtles; and biomass, 1950 tons.

4) Rate of exploitation

Present rate of exploitation = 0.125
Natural mortality coefficient = 0.105/year

5) Present status of the population

The present adult stock and total eggs spawned decreased to 40% of virginstock.

6) Diagnosis of present stock [Diagnosis 2]

Diagnosis of the status of a population is to decide:

a. overfished,
b. optimum level, or
c. under exploited.

The criterion of diagnosis is the rate of decrease of adults or total eggs spawned. From the average sustainable yield curve, it was found that a 50% level of virgin stock is an optimum level to obtain a very good sustainable yield. The present adult stock and total eggs spawned decreased to 40% of virgin stock. Accordingly, the present status need care but it is not concluded to be overfished.

7) Sustainable yield in present fisheries condition (carapace length at first capture is 50 cm) [Diagnosis 3]

5500 turtles, or 245 tons.

8) Sustainable yield when fisheries condition is changed (so as carapace length at first capture is 70 cm) [Diagnosis 4]

8-1) under the present fishing mortality coefficient

By adopting measures to limit the carapace length of catch to over 70cm (12 years), the stock number will increase by 30%, and large-sized turtleswill be available under the present fishing mortality coefficient. Catchin number is expected to decrease by 40%

(3500 individuals), and catch inweight is expected to decrease by 10% (218 tons).

Under this new regulation, although catch will decrease at first, it willincrease after 10 years.

8-2) when fishing mortality coefficient is 0.2

Sufficient number of adult stock can be maintained by adopting measures to limit the carapace length of catch to over 70cm (12 years). Thus, we can increase the fishing mortality coefficient. When the fishing mortality coefficient is 0.2, the stock number will increase by 15%, and large-sized turtles will be available. The population will increase to a level which provides sustainable yields with a 25% decreased catch in number (4100 individuals) and a little increased catch in weight (249 tons).

8-3) when fishing mortality coefficient is 0.3

When the fishing mortality coefficient is 0.3, i.e. two times the presentcoefficient, the stock number will increase slightly, and large-sized turtles will be available. The population will increase to a level whichprovides sustainable yields with a 15% decreased catch in number (4800 individuals) and a 10% increased catch in weight (274 tons).

9) Verification of the results using the adult number and the total eggs

The diagnosis of the hawksbill turtle stock was, as a effect, obtained from the holistic biological data and catch statistics, as causes, collected in Cuba, using stock model as one of the laws of nature. It must be verified that the results are correct,and akeptable in the actualphenomena. If these are deficiencies, inferionfies, or insufficiencies are found from verification, they must be reconsidered as the process of feed back for further researches.

The information on nests and eggs spawned is available in verifying the calculated results. As turtles spawn on sandy beaches, their spawning canbe easily observed. Thereby it is a more effective factor in verificationfor turtles than for fish which spawning in the sea is usually impossibleto observe. The adult stock, nests and total eggs spawned (effective eggsafter hatching) from the above described results of the population analysis are represented as follows:

Total eggs	Adult turtles		Landed adult	Nests
	total	female	females	
× 10^3	× 10^3		(one year)	× 10^3
1658	24.0	19.2	7.4	17.0

From this, the average of the landed adult females is 7400 turtles per year, but verification of this number by the survey is necessary. In theCuban archipelago,

total coastline length is 5746Km;

total sandy beach length, 1159Km; and

nest beach length, 345Km.

Therefore, the landed adult females per nest beach length per month is 4/Km/month. It is necessary to compare the calculated figures with

observed ones by actual survey. A complete count in every beaches every month is impossible, thus a sample survey method is to be introduced.

Table 3-1 Carapace length and body weight of the hawksbill sea turtle in the Cuban Archipelago

age	carapace length	body weight
1	17.0	0.6
2	25.0	2.0
3	32.2	4.3
4	38.7	7.5
5	44.6	11.4
6	49.9	16.0
7	54.7	21.1
8	59.1	26.6
9	63.0	32.3
10	66.6	38.0
11	69.8	43.8
12	72.7	49.5
13	75.3	55.0
14	77.7	60.4
15	79.8	65.6
20	87.8	87.4
30	95.6	112.6
40	98.4	122.8
50	99.4	126.7

Table 3-2 Biological information and fisheries condition of hawksbill turtle population in the Cuban Archipelago

Life span	Present survival rate	Total mortality coefficient	Survival rate of virgin stock	Natural mortality coefficient	Present fishing mortality coefficient	Full available age
50	0.78200	0.24590	0.90	0.10536	0.14054	10

Age	Weight (gr)	Maturation rate (%)	Sex ratio [♀/(♀+♂)]	Fertility	Availability Q
1	0.71	0	0.80	0	0.0000
2	2.17	0	0.80	0	0.0000
3	4.53	0	0.80	0	0.0021
4	7.78	0	0.80	0	0.0178
5	11.79	0	0.80	0	0.0462
6	16.45	0	0.80	0	0.2093
7	21.58	10	0.80	86	0.5372
8	27.06	20	0.80	86	0.5294
9	32.74	30	0.80	86	0.5696
10	38.52	40	0.80	86	1.0000
11	44.29	50	0.80	86	1.0000
12	49.98	60	0.80	86	1.0000
13	55.53	80	0.80	86	1.0000
14	60.89	100	0.80	86	1.0000
15	66.01	100	0.80	86	1.0000
16	70.89	100	0.80	86	1.0000
17	75.50	100	0.80	86	1.0000
18	79.83	100	0.80	86	1.0000
19	83.89	100	0.80	86	1.0000
20	87.68	100	0.80	86	1.0000
21	91.19	100	0.80	86	1.0000
22	94.45	100	0.80	86	1.0000
23	97.46	100	0.80	86	1.0000
24	100.24	100	0.80	86	1.0000
25	102.80	100	0.80	86	1.0000
26	105.14	100	0.80	86	1.0000
27	107.30	100	0.80	86	1.0000
28	109.27	100	0.80	86	1.0000
29	111.07	100	0.80	86	1.0000
30	112.71	100	0.80	86	1.0000

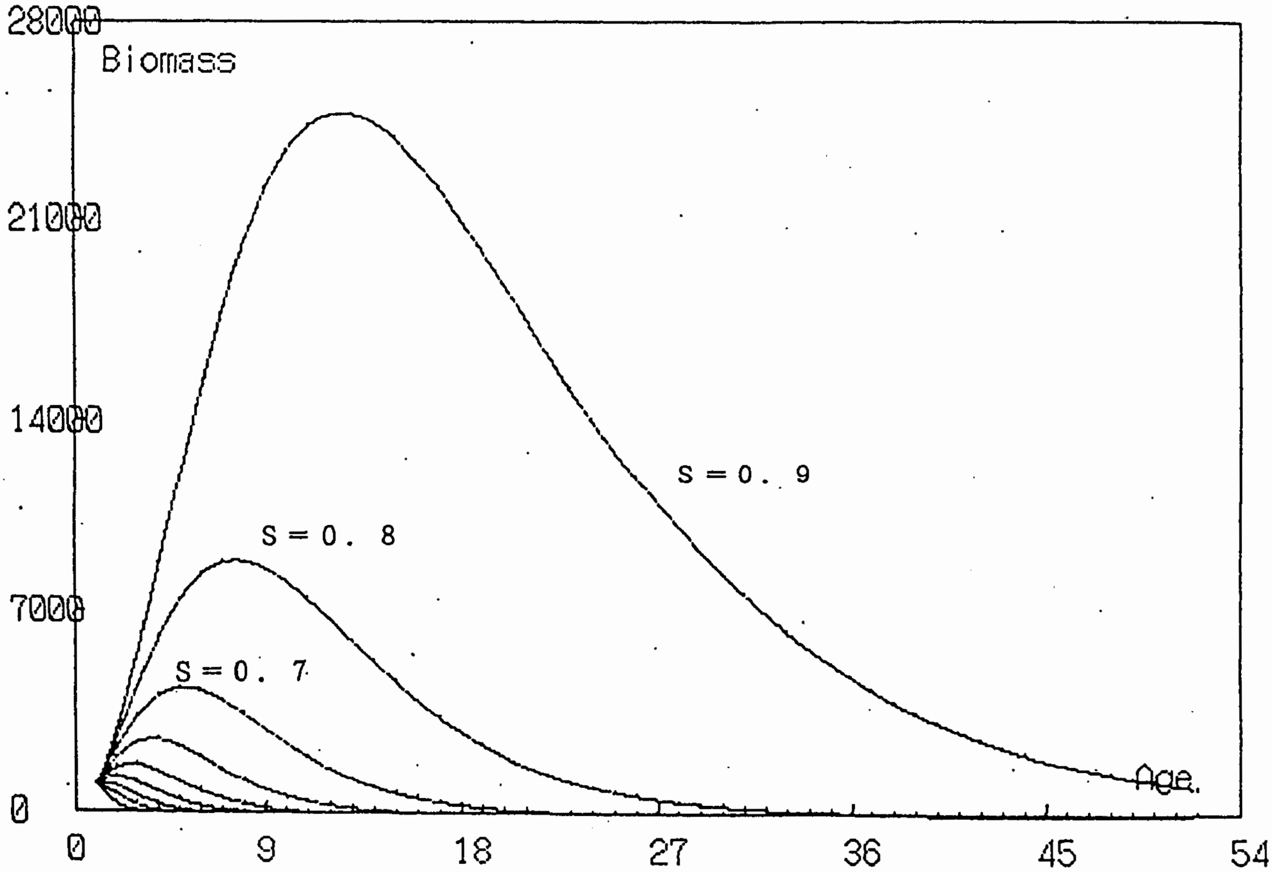

Fig.3-1 Biomass curve of the hawksbill sea turtle

Table 3-3 Age composition of hawksbill turtle in the Cuban Archipelago

Age	Frequency	Age	Frequency
1	0	16	116
2	0	17	173
3	4	18	122
4	30	19	56
5	70	20	62
6	284	21	27
7	638	22	36
8	526	23	41
9	474	24	24
10	693	25	12
11	579	26	20
12	636	27	0
13	402	28	10
14	580	29	0
15	279	30	7

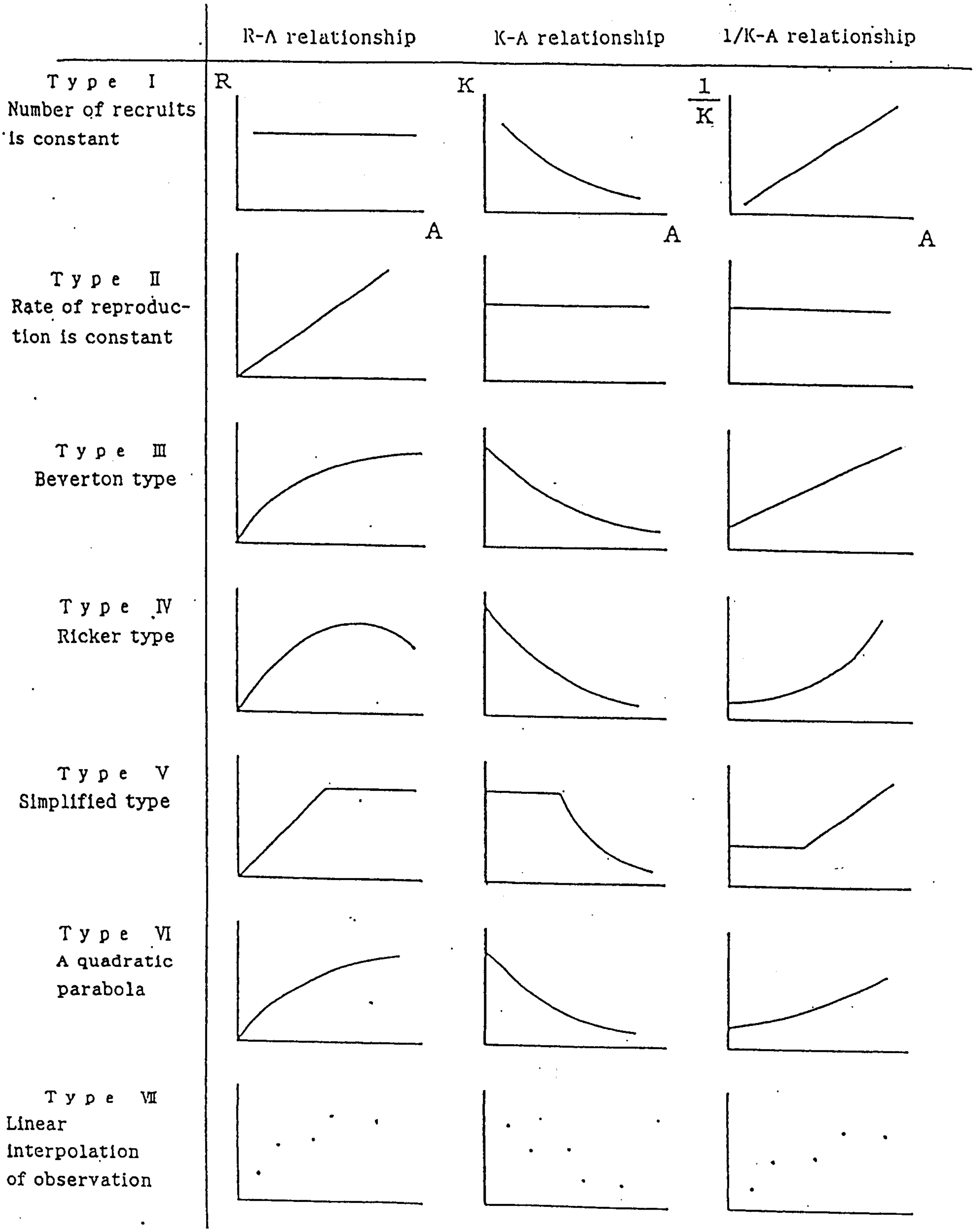

Fig.3-2 Various patterns of the reproduction curve

Table 3-4 Present status of hawksbill turtle population in the Cuban Archipelago

Fishing mortality coefficient F=0.1405

Age (year) t	Population in the Sea: Number (×10⁴) N	Population in the Sea: Weight (ton) P	Catchable stock: Number (×10⁴) NC	Catchable stock: Weight (ton) PC	Catch: Number (×10⁴) C	Catch: Weight (ton) Y	Adult: Number (×10⁴) A	Adult: Weight (ton) AW	Numbers of spawning (×10⁴) EGG
1	1.99	14.23	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	1.79	38.79	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	1.61	73.07	0.00	0.16	0.00	0.02	0.00	0.00	0.00
4	1.45	112.83	0.03	2.00	0.00	0.25	0.00	0.00	0.00
5	1.30	153.65	0.06	7.09	0.01	0.88	0.00	0.00	0.00
6	1.17	191.64	0.24	40.11	0.03	5.00	0.00	0.00	0.00
7	1.02	220.13	0.55	118.25	0.07	14.73	0.10	22.01	7.02
8	0.85	230.88	0.45	122.23	0.06	15.23	0.17	46.18	11.74
9	0.71	233.99	0.41	133.28	0.05	16.61	0.21	70.20	14.75
10	0.60	229.25	0.60	229.25	0.07	28.56	0.24	91.70	16.38
11	0.47	206.15	0.47	206.15	0.06	25.69	0.23	103.08	16.01
12	0.36	181.93	0.36	181.93	0.05	22.67	0.22	109.16	15.02
13	0.28	158.06	0.28	158.06	0.04	19.69	0.23	126.45	15.67
14	0.22	135.52	0.22	135.52	0.03	16.89	0.22	135.52	15.31
15	0.17	114.90	0.17	114.90	0.02	14.32	0.17	114.90	11.98
16	0.14	96.49	0.14	96.49	0.02	12.02	0.14	96.49	9.36
17	0.11	80.36	0.11	80.36	0.01	10.01	0.11	80.36	7.32
18	0.08	66.45	0.08	66.45	0.01	8.28	0.08	66.45	5.73
19	0.07	54.60	0.07	54.60	0.01	6.80	0.07	54.60	4.48
20	0.05	44.63	0.05	44.63	0.01	5.56	0.05	44.63	3.50
21	0.04	36.30	0.04	36.30	0.00	4.52	0.04	36.30	2.74
22	0.03	29.40	0.03	29.40	0.00	3.66	0.03	29.40	2.14
23	0.02	23.72	0.02	23.72	0.00	2.96	0.02	23.72	1.67
24	0.02	19.08	0.02	19.08	0.00	2.38	0.02	19.08	1.31
25	0.01	15.30	0.01	15.30	0.00	1.91	0.01	15.30	1.02
26	0.01	12.24	0.01	12.24	0.00	1.52	0.01	12.24	0.80
27	0.01	9.77	0.01	9.77	0.00	1.22	0.01	9.77	0.63
28	0.01	7.78	0.01	7.78	0.00	0.97	0.01	7.78	0.49
29	0.01	6.18	0.01	6.18	0.00	0.77	0.01	6.18	0.38
30	0.00	4.91	0.00	4.91	0.00	0.61	0.00	4.91	0.30
Total	14.6	2802.2	4.5	1956.2	0.6	243.7	2.4	1326.4	165.8

E	R/A	R/HH x(1/10000)	R x10000	A x10000	HH x10000	Survival rate from 0 to 1 year
0.1246	0.8262	120.0910	1.99	2.41	165.76	0.012009100

E: Rate of exploitation; R/A, R/HH: Reproduction rate;
R: Number of recruits; A: Adult stock in number;
HH: Total eggs spawned.

Table 3-5 [illegible]stainable yield at various fishing mortalities (F)

---SY table---

Fishing mortality coefficient F (year^{-1})	Adult stock Number (×10^4) A	Adult stock Weight (ton) AW	Catch Number (×10^4) C	Catch Weight (ton) Y	Reproduction rate K	Production parameter Y/F
0.000	6.25	4389.65	0.00	0.00	0.2848	4.95
0.020	5.28	3577.05	0.15	82.17	0.3492	4108.73
0.040	4.52	2951.17	0.26	138.25	0.4182	3456.30
0.060	3.91	2463.84	0.34	176.75	0.4915	2945.90
0.080	3.42	2080.27	0.41	203.33	0.5684	2541.66
0.100	3.02	1775.15	0.47	221.76	0.6488	2217.57
0.120	2.69	1529.90	0.51	234.56	0.7323	1954.64
0.140	2.42	1330.79	0.55	243.45	0.8186	1738.89
0.141	2.40	1184.15	0.55	243.24	0.8262	1725.14
0.141	2.20	1085.47	0.51	222.97	0.8262	1581.38
0.141	2.00	986.79	0.46	202.70	0.8262	1437.61
0.141	1.80	888.11	0.42	182.43	0.8262	1293.85
0.141	1.60	789.43	0.37	162.16	0.8262	1150.09
0.141	1.40	690.75	0.32	141.89	0.8262	1006.33
0.141	1.20	592.07	0.28	121.62	0.8262	862.57
0.141	1.00	493.40	0.23	101.35	0.8262	718.81
0.141	0.80	394.72	0.18	81.08	0.8262	575.05
0.141	0.60	296.04	0.14	60.81	0.8262	431.28
0.141	0.40	197.36	0.09	40.54	0.8262	287.52
0.141	0.20	98.68	0.05	20.27	0.8262	143.76
Present 0.141	2.41	1326.39	0.56	243.72	0.8262	1734.20

Table 3-6 Sustainable Yield when fisheries condition is changed (size limitation is 70cm)

---SY table---

Fishing mortality coefficient F ($year^{-1}$)	Adult stock Number ($\times 10^4$) A	Adult stock Weight (ton) AW	Catch Number ($\times 10^4$) C	Catch Weight (ton) Y	Reproduction rate K	Production parameter Y/F
0.000	6.25	4389.65	0.00	0.00	0.2848	4.08
0.020	5.62	3816.13	0.10	69.98	0.3284	3499.18
0.040	5.10	3354.28	0.17	121.30	0.3708	3032.50
0.060	4.67	2979.10	0.23	159.28	0.4116	2654.62
0.080	4.31	2671.66	0.28	187.66	0.4507	2345.76
0.100	4.01	2417.56	0.32	209.10	0.4882	2090.98
0.120	3.76	2205.75	0.35	225.47	0.5239	1878.88
0.140	3.54	2027.73	0.37	238.10	0.5580	1700.74
0.160	3.35	1876.91	0.40	247.97	0.5906	1549.83
0.180	3.19	1748.14	0.41	255.77	0.6216	1420.94
0.200	3.05	1637.39	0.43	262.00	0.6513	1309.98
0.220	2.92	1541.47	0.44	267.03	0.6795	1213.75
0.240	2.81	1457.84	0.46	271.13	0.7065	1129.71
0.260	2.72	1384.48	0.47	274.51	0.7323	1055.82
0.280	2.63	1319.74	0.48	277.33	0.7570	990.46
0.300	2.55	1262.31	0.49	279.69	0.7805	932.30
0.320	2.48	1211.10	0.50	281.69	0.8031	880.28
0.340	2.41	1165.21	0.50	283.40	0.8246	833.51
0.340	2.20	941.58	0.46	258.69	0.8246	760.85
0.340	2.00	855.99	0.42	235.17	0.8246	691.68
0.340	1.80	770.39	0.38	211.66	0.8246	622.52
0.340	1.60	684.79	0.33	188.14	0.8246	553.35
0.340	1.40	599.19	0.29	164.62	0.8246	484.18
0.340	1.20	513.59	0.25	141.10	0.8246	415.01
0.340	1.00	427.99	0.21	117.59	0.8246	345.84
0.340	0.80	342.39	0.17	94.07	0.8246	276.67
0.340	0.60	256.80	0.13	70.55	0.8246	207.51
0.340	0.40	171.20	0.08	47.03	0.8246	138.34
0.340	0.20	85.60	0.04	23.52	0.8246	69.17

Table 3-7 Estimate of future stock by regulation
of carapace length (70cm)----(1)

Fishing mortality coefficient F= 0.1405

years		Age 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	total	adult
1	N	19900	17910	16119	14503	13022	11649	10197	8530	7145	5950	4653	3639	2845	2225	1740	1361	146267	24240
	P	14	39	73	113	154	192	220	231	234	229	206	182	158	136	115	96	2820	-
	C	0	0	0	0	0	0	0	0	0	0	290	453	355	277	217	170	2369	-
	Y	0	0	0	0	0	0	0	0	0	0	13	23	20	17	14	12	152	-
3	N	19900	17910	16119	14507	13056	11748	10548	9436	8259	6910	5787	4503	3060	2225	1740	1361	151949	26433
	P	14	39	73	113	154	193	228	255	271	266	256	225	170	136	115	96	3033	-
	C	0	0	0	0	0	0	0	0	0	0	361	561	381	277	217	170	2574	-
	Y	0	0	0	0	0	0	0	0	0	0	16	23	21	17	14	12	162	-
5	N	19900	17910	16119	14507	13056	11751	10576	9515	8544	7643	6690	5230	3806	2754	1871	1361	156113	28974
	P	14	39	73	113	154	193	228	258	280	295	296	262	211	168	124	96	3232	-
	C	0	0	0	0	0	0	0	0	0	0	417	652	474	343	233	170	2896	-
	Y	0	0	0	0	0	0	0	0	0	0	13	33	26	21	15	12	179	-
7	N	19900	17910	16119	14507	13056	11751	10576	9518	8566	7708	6921	5785	4400	3198	2327	1684	158886	31235
	P	14	39	73	113	154	193	228	258	281	297	307	289	244	195	154	119	3393	-
	C	0	0	0	0	0	0	0	0	0	0	431	721	548	398	230	210	3216	-
	Y	0	0	0	0	0	0	0	0	0	0	19	36	30	24	19	15	198	-
10	N	19900	17910	16119	14507	13056	11751	10576	9518	8566	7710	6939	5835	4562	3559	2766	2104	161198	33484
	P	14	39	73	113	154	193	228	258	281	297	307	292	253	217	183	149	3554	-
	C	0	0	0	0	0	0	0	0	0	0	432	727	568	443	345	262	3503	-
	Y	0	0	0	0	0	0	0	0	0	0	19	36	32	27	23	19	218	-

N : Population number P : Population weight in tons C : Catch in number Y : Catch in tons adult : Total number of adults
total : The sum from 1 to 30 years

Table 3-7 Estimate of future stock by regulation of carapace length (70cm)----(2)

Fishing mortality coefficient F= 0.2

years		Age 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	total	adult
1	N	19900	17910	16119	14503	13022	11649	10197	8530	7145	5950	4653	3639	2845	2225	1740	1361	146267	24240
	P	14	39	73	113	154	192	220	231	234	229	206	182	158	136	115	96	2820	-
	C	0	0	0	0	0	0	0	0	0	0	401	627	490	383	300	235	3277	-
	Y	0	0	0	0	0	0	0	0	0	0	18	31	27	23	20	17	210	-
3	N	19900	17910	16119	14507	13056	11748	10548	9436	8259	6910	5787	4383	2806	1976	1545	1208	150430	25013
	P	14	33	73	113	154	193	228	255	271	266	256	219	156	120	102	86	2926	-
	C	0	0	0	0	0	0	0	0	0	0	499	755	484	340	266	208	3299	-
	Y	0	0	0	0	0	0	0	0	0	0	22	38	27	21	18	15	205	-
5	N	19900	17910	16119	14507	13056	11751	10576	9515	8544	7643	6690	5090	3490	2380	1524	1073	153613	26594
	P	14	39	73	113	154	193	228	258	280	295	296	254	194	145	101	76	3051	-
	C	0	0	0	0	0	0	0	0	0	0	576	877	601	410	263	185	3576	-
	Y	0	0	0	0	0	0	0	0	0	0	26	44	33	25	17	13	217	-
7	N	19900	17910	16119	14507	13056	11751	10576	9518	8566	7708	6921	5630	4034	2763	1895	1292	155644	28128
	P	14	39	73	113	154	193	228	258	281	297	307	282	224	168	125	92	3153	-
	C	0	0	0	0	0	0	0	0	0	0	596	970	695	476	327	223	3890	-
	Y	0	0	0	0	0	0	0	0	0	0	26	49	39	29	22	16	233	-
10	N	19900	17910	16119	14507	13056	11751	10576	9518	8566	7710	6939	5679	4183	3075	2252	1614	157135	29560
	P	14	39	73	113	154	193	228	258	281	297	307	284	232	187	149	114	3248	-
	C	0	0	0	0	0	0	0	0	0	0	598	979	721	530	388	278	4146	-
	Y	0	0	0	0	0	0	0	0	0	0	26	49	40	32	26	20	249	-

N : Population number P : Population weight in tons C : Catch in number Y : Catch in tons adult : Total number of adults
total : The sum from 1 to 30 years

Table 3-7 Estimate of future stock by regulation
of carapace length (70cm)----(3)

Fishing mortality coefficient F= 0.3

years		Age 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	total	adult
1	N	19900	17910	16119	14503	13022	11649	10197	8530	7145	5950	4653	3639	2845	2225	1740	1361	146267	24240
	P	14	39	73	113	154	192	220	231	234	229	206	182	158	136	115	96	2820	-
	C	0	0	0	0	0	0	0	0	0	0	574	897	702	549	429	336	4698	-
	Y	0	0	0	0	0	0	0	0	0	0	25	45	39	33	28	24	301	-
3	N	19900	17910	16119	14507	13056	11748	10548	9436	8259	6910	5787	4195	2430	1617	1265	989	148224	22957
	P	14	39	73	113	154	193	228	255	271	266	256	210	135	99	84	70	2771	-
	C	0	0	0	0	0	0	0	0	0	0	714	1035	599	399	312	244	4177	-
	Y	0	0	0	0	0	0	0	0	0	0	32	52	33	24	21	17	256	-
5	N	19900	17910	16119	14507	13056	11751	10576	9515	8544	7643	6690	4872	3023	1865	1080	719	150348	23510
	P	14	39	73	113	154	193	228	258	280	295	296	244	168	114	71	51	2817	-
	C	0	0	0	0	0	0	0	0	0	0	825	1202	746	460	266	177	4312	-
	Y	0	0	0	0	0	0	0	0	0	0	37	60	41	28	18	13	252	-
7	N	19900	17910	16119	14507	13056	11751	10576	9518	8566	7708	6921	5389	3494	2166	1344	829	151698	24387
	P	14	39	73	113	154	193	228	258	281	297	307	269	194	132	89	59	2869	-
	C	0	0	0	0	0	0	0	0	0	0	853	1329	862	534	331	204	4594	-
	Y	0	0	0	0	0	0	0	0	0	0	38	66	48	33	22	14	263	-
10	N	19900	17910	16119	14507	13056	11751	10576	9518	8566	7710	6939	5436	3623	2410	1597	1036	152515	25149
	P	14	39	73	113	154	193	228	258	281	297	307	272	201	147	105	73	2913	-
	C	0	0	0	0	0	0	0	0	0	0	856	1341	894	594	394	255	4793	-
	Y	0	0	0	0	0	0	0	0	0	0	38	67	50	36	26	18	274	-

N : Population number P : Population weight in tons C : Catch in number Y : Catch in tons adult : Total number of adults
total : The sum from 1 to 30 years

Appendix 1

Age x	Availability Q	Maturity $MTR(x)$	Individual weight $W(x)$	Number in the sea	Adults	Weight in catchable phase
1	Q_1	$MTR(1)$	$W(1)$	N_1	$MTR(1)N_1$	$N_1Q_1W(1)$
2	Q_2	$MTR(2)$	$W(2)$	$N_2=N_1[Q_1S+(1-Q_1)S_0]$	$MTR(2)N_2$	$N_2Q_2W(2)$
3	Q_3	$MTR(3)$	$W(3)$	$N_3=N_2[Q_2S+(1-Q_2)S_0]$ $=N_1[Q_1S+(1-Q_1)S_0][Q_2S+(1-Q_2)S_0]$	$MTR(3)N_3$	$N_3Q_3W(3)$
.	.	.	.	.	.	.
.	.	.	.	.	.	.
.	.	.	.	.	.	.
λ	Q_λ	$MTR(\lambda)$	$W(\lambda)$	$N_\lambda=N_{\lambda-1}[Q_{\lambda-1}S+(1-Q_{\lambda-1})S_0]$ $=N_1\prod_{x=2}^{\lambda-1}[Q_xS+(1-Q_x)S_0]$	$MTR(\lambda)N_\lambda$	$N_\lambda Q_\lambda W(\lambda)$
Total	–	–	–	$N=\sum_{x=1}^{\lambda}N_x$	$A=\sum_{x=1}^{\lambda}MTR(x)N_x$	$P=\sum_{x=1}^{\lambda}N_xQ_xW(x)$