The Regional Organization for the Conservation of the Environment of the Red Sea and Gulf of Aden (PERSGA)

Regional Training Courses on Elasmobranch Identification, Sampling and Stock Assessment Methods

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Aden, 28 April – 1 May 2001

Aden, 27 April – 2 May 2002

Trainer: Dr. Ramón Bonfil

PERSGA Training Workshop Report

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PERSGA, The Regional Organization for the Conservation of the Environment of the Red Sea and Gulf of Aden, is an intergovernmental organisation dedicated to the conservation of the coastal and marine environments in the region. The Organization was officially established in 1995.

Since December 1998, PERSGA has been the executing agency for The Strategic Action Programme for the Red Sea and Gulf of Aden (SAP). This Programme is funded jointly by the member countries of PERSGA, the Global Environment Facility (GEF) and the Islamic Development Bank. The GEF implementing agencies include the United Nations Development Programme, the United Nations Environment Programme, and the World Bank.

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ABSTRACT

This report provides a summary of two PERSGA Training Courses held at the regional training centre in Aden in April 2001 and April 2002. The aim of the first course was to train enumerators and other fisheries staff in the correct identification of elasmobranchs and the methodology used for their sampling in the field. The aim of the second course was to train regional fisheries staff and scientists in stock assessment methods thereby increasing the technical capacity for the long-term management of regional elasmobranch resources.

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INTRODUCTION

The elasmobranch fisheries of the Red Sea and Gulf of Aden are among the most important in the region in terms of catches, employment and economic revenue. They have run unregulated for decades, increasing in size and range and achieving relatively high levels of exploitation. Undesirable fishing practices are also used. The observed trends in regional shark and ray fisheries carry the consequent risk of over-exploitation and depletion of the resource posing the threat of economic and social hardship that always follows fishery collapses. There is a pressing need to implement elasmobranch fisheries management and conservation in the Region.

Poor management of shark and ray fisheries resources is not restricted to the Red Sea and Gulf of Aden but is a worldwide problem. The need for urgent action to alleviate this global problem has been pointed out at several international fora. Within this context the Food and Agriculture Organisation of the United Nations has called for member countries to subscribe to the International Plan of Action for the Conservation and Management of Sharks (FAO 1999). As stated in that document, one of the many reasons behind the absence of management of shark resources in most parts of the world is the widespread lack of technical skills in stock assessment in many fishing nations. Experience in stock assessment of shark resources has only started to accumulate and disseminate in the last decade.

The countries of the region need to comply with FAO's Technical Guidelines for Responsible Fisheries and the International Plan of Action for the Conservation and Management of Sharks (IPOA-Sharks). Both initiatives call for shark and ray fisheries to record catch and effort information and to perform stock assessment on a species by species basis. This will enable proper species-specific data to be produced as a first step towards fisheries management of elasmobranch populations in the region.

Sharks and batoids are a group of fishes that are very fragile and sensitive to fisheries exploitation. Historical data show they have been overexploited in many parts of the world (STEVENS et al. 2000). Every species has different population dynamics, therefore responds differently to exploitation. Many species grow very slowly and take many years to reproduce (Table 1). Sharks and rays have very few young (between 1 and 80, usually about 12) every time they reproduce. Other marine organisms release millions of eggs into the water and potentially produce large recruitments. For these reasons shark and batoid populations take many years to recover once overexploited.

The shark and ray fauna of the Red Sea and Gulf of Aden although incompletely known is quite diverse. Many of the commercially important species of sharks belong to the family Carcharhinidae, which are difficult to distinguish from each other.

There are great problems with the systems for collecting and reporting fisheries data among some of the PERSGA member countries. There is sometimes a mismatch between data reported by each country and data from FAO. In the worst cases, there is no collection and reporting of data on elasmobranch catches although landings are known to occur. This is a particularly acute problem in Yemen because it has the most sizeable shark fishing fleets. The same problem also occurs in Sudan and Somalia.

Table 1: Rebound potential (r_{2M}) of Pacific sharks as a function of life history parameters (© CSIRO 1998; modified with permission of CSIRO Publishing, from *Marine and Freshwater Research* 49: 663-678 (Smith, S.E. Au, D.W. & C Show. Intrinsic rebound potentials of 26 species of Pacific sharks).

Relative r_{2M}	Species	Female age at maturity	Longevity	Fecundity	M	r_{2M}
High	Grey smoothhound	2	12	3.2	0.368	0.136
	Brown smoothhound	2	15	3.8	0.295	0.127
	Bonnethead	3	12	9.0	0.368	0.105
	Sharpnose	4	10	5.0	0.440	0.084
Medium	Common thresher	5	19	4.0	0.234	0.069
	Oceanic whitetip	5	22	6.0	0.203	0.067
	Blue	6	20	23.2	0.223	0.061
	Blacktip	7	18	5.2	0.247	0.054
	Grey reef	7	18	5.0	0.247	0.054
	Sand tiger	6	35	2.0	0.129	0.052
	Mako	7	28	8.0	0.160	0.051
	Whitetip reef	8	16	2.2	0.277	0.048
	Galapagos	8	24	8.0	0.186	0.048
	Silky	9	25	5.2	0.179	0.043
	Tiger	9	28	34.4	0.160	0.043
	Great white	9	36	7.0	0.125	0.040
Low	Pacific Angel	10	35	6.0	0.129	0.038
	Lemon	12	25	8.2	0.179	0.034
	Spiny dogfish (Northwest Atlantic)	10	50	6.0	0.091	0.034
	Soupfin (school)	12	40	28.0	0.113	0.033
	Leopard	13	30	12.0	0.150	0.032
	Sandbar	15	30	7.8	0.150	0.028
	Scalloped Hammerhead	15	35	21.6	0.129	0.028
	Bull	15	27	3.6	0.166	0.027
	Sevengill	16	32	88.2	0.140	0.026
	Dusky	21	40	6.4	0.113	0.020
	Spiny dogfish (British Columbia)	25	70	7.2	0.065	0.017

No country in the region has any kind of species-specific catch data for elasmobranchs. Even Saudi Arabia, apparently with the best data recording system in the region, usually reports only sharks and rays together as one item although occasionally sharks and rays appear as separate items. The separation of data by species groups, needed for stock assessment and management, is non-existent.

If member countries aim to perform assessments of the status of their elasmobranch resources (and if they plan to comply with FAO's International Plan of Action for the

Conservation and Management of Sharks [IPOA-Sharks]), it is imperative that the catches are recorded in main species or main species groups.

The Strategic Action Programme (SAP) for the Red Sea and Gulf of Aden aims to upgrade regional joint efforts in the conservation of marine biological resources. Three trips were made to the region with the major goals of preparing an identification guide to the elasmobranchs of the Red Sea and Gulf of Aden region (RSGA) and providing theoretical and practical training to national and regional staff on shark identification, sampling techniques, stock assessment and management. Within this context, two training courses were organised by the SAP Living Marine Resources (LMR) component.

The first course, on species identification and fisheries sampling methods, took place from 28 April – 1 May 2001. The second, on stock assessment of shark and ray fishery resources, was held from 27 April – 2 May 2002. Both courses were conducted by Dr. Ramón Bonfil at the regional Research and Training Centre in Aden.

COURSE 1 – ELASMOBRANCH SPECIES IDENTIFICATION AND SAMPLING METHODS

Course Objectives

There is a particular need for catch data to be reported in terms of the main species and species groups. The aims of the 3-day course in 2001 were therefore to train regional fisheries enumerators and other interested staff to identify the sharks and batoids of the region and to record the biological information required for stock assessment and management. The course took place at the Sub-Regional Training Centre in Aden between April 28 and May 1, 2001. Fifty-two trainees from different countries within the region attended the course.

Course Schedule

Saturday

a) 10:30 am to 12:30 pm

b) 2:00 pm to 6:00 pm

Sunday and Monday

a) 8:30 am – 10 am

b) 10:30 am – 12:30 pm

c) 2:00 pm – 6:00 pm

Morning sessions focused on theory while the afternoon sessions were a mixture of theory and practical work.

Course description

General remarks

Trainees were provided with a copy of the draft *Field Identification Guide to the Sharks and Rays of the Red Sea and Gulf of Aden*. A total of 39 shark and 35 batoid species are included in the guide. This document should enable them (with the techniques and tricks of the trade learned during this course) to identify all the species encountered in the commercial catches. A copy of the guide is available in PDF format from the PERSGA website www.persga.org.

The course consisted of two sections. In part one, lecture and practical sessions were given in identification, and in basic shark anatomy and biology. More than 60 fresh specimens, representing 14 shark and 7 batoid species, were used in the laboratory sessions. These specimens were kindly collected at fish markets and landing sites by Mr. Murtada Ahmed in Hodeidah and by Mr. Hashem Al-Saqqaf in Aden.

The second part of the course focussed on the methods and techniques used for collecting information on the biology, meristics and fisheries.

Course Outline

Part 1 - Species Identification

The course covered the following topics, (not all included in this document):

Technical terms for typical sharks and batoids: the anatomical terminology needed for identification and sampling.

Elasmobranch diversity - taxonomy of sharks and batoids: the diversity of elasmobranch designs and how they are classified into broad groups.

Most useful characters for shark identification: the key characters most frequently used for shark identification.

Orders of sharks found in the region: the key characteristics of each of the four orders of sharks known from the region.

Families of sharks found in the region: the key characteristics of each of the 13 families of sharks known from the region.

Species easy to identify: members of the families Heterodontidae, Odontaspididae, Lamnidae, Stegostomatidae, Ginglymostomatidae, and Rhincodontidae.

Species difficult to identify: Alopiidae (thresher sharks), Scyliorhinidae and Proscyllidae (Catsharks and finback catsharks), Triakidae and Carcharhinidae (smoothhounds and requiem sharks), Sphyrnidae (hammerhead sharks)

Orders of batoids found in the region: the key characteristics of each of the four orders of batoids known from the region.

Families of batoids found in the region: the key characteristics of each of the nine families of batoid fishes known from the region.

Part 2 - Biological sampling and fisheries sampling

Types of data needed for stock assessment: the kinds of data needed for the different stages of stock assessment:

a) life history (age, growth, reproduction, feeding habits, nursery areas, migrations),
b) catch in weight by main species,
c) length composition of main species,
d) fishing effort.

Common measurements for sharks and rays: methods for proper measurement of lengths and other relevant meristics of sharks and batoids.

Introduction to sampling design techniques: the main approaches to sampling fishery data:

a) census sampling,
b) simple random sampling,
c) stratified random sampling.

Sampling catch composition: rapid methods for assessing the composition of the catch by main species:

a) estimation of the number of specimens of each species in the catch,
b) estimation of total weight of each species.

Sampling length composition of the main species: data used for length-based methods and to assess which part of the population is being exploited.

Sampling fishing effort: main measures of effort in order of preferred level of detail:

a) total fishing hours per gear,
b) total number of sets of data,
c) total number of trips,
d) total number of vessels per gear category,
e) sampling economic data,
f) ex-vessels prices for main species,
g) costs of fishing,
h) number of fishermen participating in the fishery,
i) number of processors involved in value-added activities.

SHARK AND BATOID DIVERSITY

There are at least 460 different species of sharks recognised by science. The batoids (skates, rays, mantas and guitarfishes) are also part of the elasmobranch group. They are a group of almost 600 species of flat "sharks". In the RSGA region there are at least 44 different species of shark and about 30 species of batoids (Table 2). The list keeps growing as new species are discovered.

Table 2: List of families and species of elasmobranchs in the Red Sea and Gulf of Aden

An asterix indicates that a species account is given in the above-mentioned guide. A question mark indicates that presence in the area needs confirmation.

SHARKS		**BATOIDS**	
Order Squaliformes		Order Pristiformes	
	Echinorhinidae		**Pristidae**
*	*Echinorhinus brucus*	*	*Anoxypristis cuspidata*
	Centrophoridae	*	*Pristis pectinata*
*	*Centrophorus atromarginatus*	*	*Pristis zijsron*
*	*Centrophorus granulosus*	Order Torpediniformes	
*	*Centrophorus tessellatus*		**Torpedinidae**
*	*Deania profundorum*	*	*Torpedo panthera*
Order Squatiniformes		*	*Torpedo sinuspersici*
	Squatinidae		**Narkidae**
?	*Squatina africana*	*	*Heteronarce bentuviai*
?	*Squatina squatina*	Order Rhinobatiformes	
Order Heterodontiformes			**Rhinobatidae**
	Heterodontidae	?	*Rhinobatos cemiculus*
*	*Heterodontus ramalheira*	?*	*Rhinobatos granulatus*
*	*Heterodontus* sp A	*	*Rhinobatos halavi*
Order Lamniformes		?	*Rhinobatos obtusus*
	Odontaspididae	*	*Rhinobatos punctifer*
*	*Carcharias taurus*	?*	*Rhinobatos salalah*
	Alopiidae	?*	*Rhinobatos schlegelii*
*	*Alopias pelagicus*	?*	*Rhinobatos thouin*
*	*Alopias superciliosus*		**Rhynchobatidae**
*	*Alopias vulpinus*	*	*Rhina ancylostoma*
	Lamnidae	?	*Rhyncobatus australiae*
?	*Carcharodon carcharias*	*	*Rhyncobatus djiddensis*
*	*Isurus oxyrinchus*	Order Myliobatiformes	
Order Orectolobiformes			**Dasyatidae**
	Stegostomatidae	*	*Dasyatis kuhlii*
*	*Stegostoma fasciatum*	?	*Dasyatis pastinaca*
	Ginglymostomatidae	*	*Himantura fai*
*	*Nebrius ferrugineus*	*	*Himantura gerrardi*

SHARKS		**BATOIDS**	
	Rhincodontidae	*	*Himantura imbricata*
*	*Rhincodon typus*	*	*Himantura uarnak*
Order Carcharhiniformes		*	*Pastinachus sephen*
	Scyliorhinidae	?	*Taeniura grabata*
*	*Halaelurus boesemani*	*	*Taeniura lymma*
*	*Apristurus indicus*	*	*Taeniura meyeni*
	Proscyllidae	*	*Urogymnus asperrimus*
*	*Eridacnis radcliffei*		**Gymnuridae**
	Triakidae		*Aetoplatea tentaculata*
*	*Iago omanensis*	*	*Gymnura poecilura*
*	*Mustelus mosis*		**Myliobatidae**
	Hemigaleidae	*	*Aetobatus flagellum*
*	*Hemigaleus microstoma*	*	*Aetobatus narinari*
*	*Hemipristis elongatus*	?	*Aetobatus ocellatus*
	Carcharhinidae	*	*Aetomylaeus milvus*
*	*Carcharhinus albimarginatus*	*	*Aetomylaeus vespertilio*
*	*Carcharhinus altimus*		**Rhinopteridae**
*	*Carcharhinus amblyrhynchoides*	*	*Rhinoptera javanica*
*	*Carcharhinus amblyrhynchos*	*	*Rhinoptera jayakari*
*	*Carcharhinus amboinensis*		**Mobulidae**
*	*Carcharhinus brevipinna*	*	*Manta birostris*
*	*Carcharhinus dussumieri*	*	*Mobula eregoodootenkee*
*	*Carcharhinus falciformis*	*	*Mobula japanica*
*	*Carcharhinus leucas*	?	*Mobula kuhlii*
*	*Carcharhinus limbatus*	*	*Mobula tarapacana*
*	*Carcharhinus longimanus*		
?	*Carcharhinus macloti*		
*	*Carcharhinus melanopterus*		
?	*Carcharhinus obscurus*		
*	*Carcharhinus plumbeus*		
*	*Carcharhinus sealei*		
*	*Carcharhinus sorrah*		
*	*Galeocerdo cuvier*		
*	*Loxodon macrorhinus*		
*	*Negaprion acutidens*		
*	*Triaenodon obesus*		
*	*Rhizoprionodon acutus*		
	Sphyrnidae		
*	*Sphyrna lewini*		
*	*Sphyrna mokarran*		

SPECIES IDENTIFICATION

Basic terminology of shark anatomy

Figure 1: Ventral view of a generalised shark

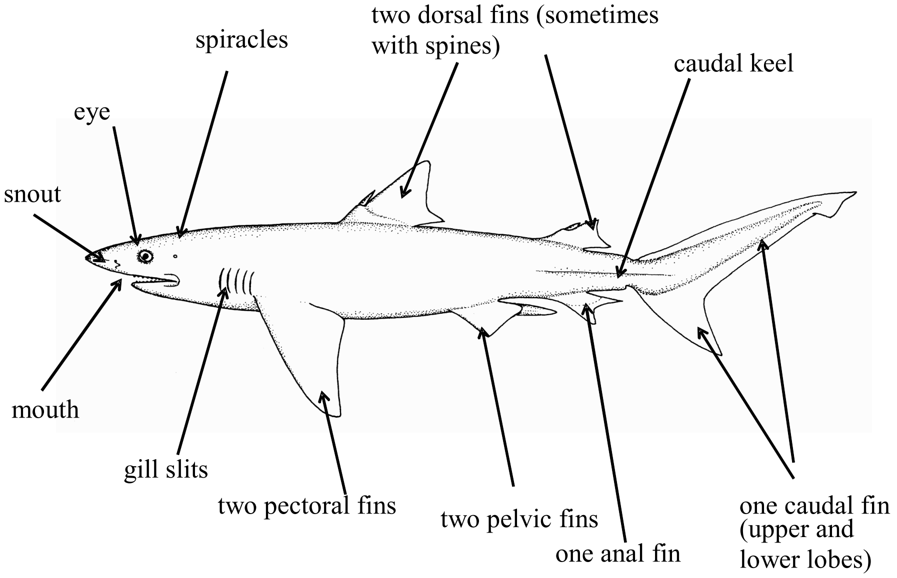


Figure 2: View of underside of a generalised shark

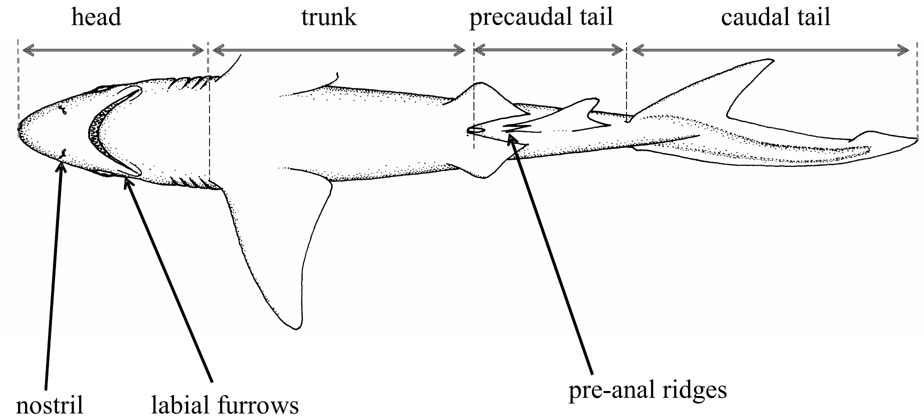
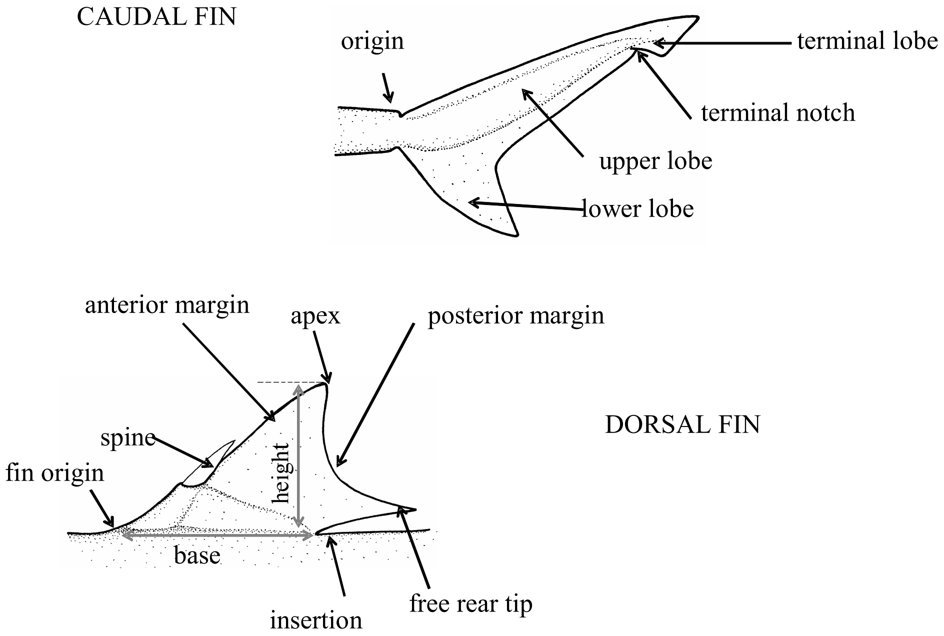


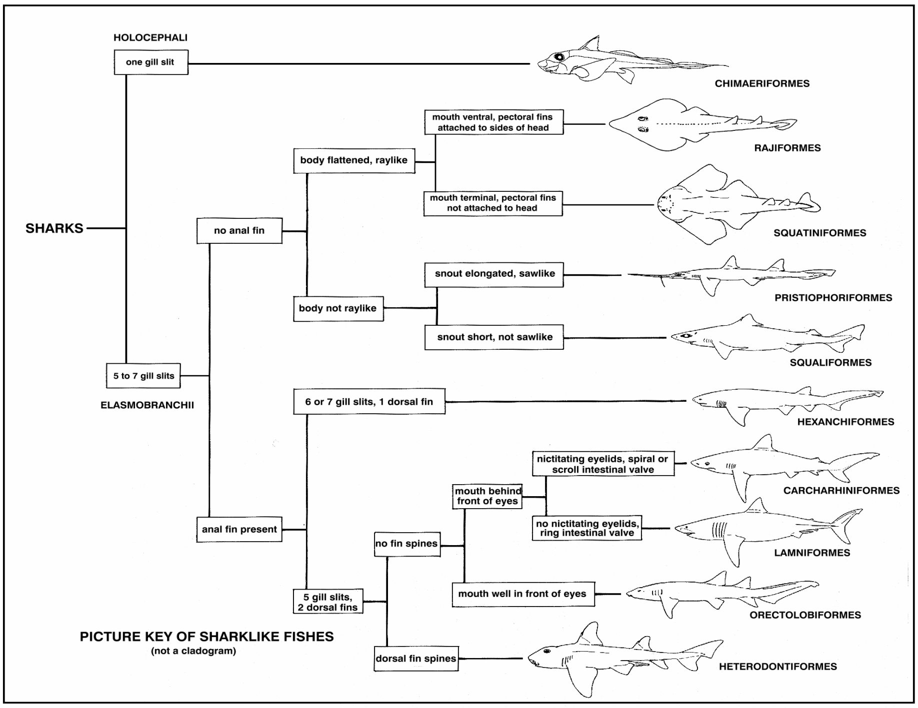
Figure 3: Fins of a generalised shark



Shark and batoid Classification

‘Typical’ sharks are classified into eight orders (Figure 4) four of which are found in the region, 35 families (13 found in the region) and more than 99 genera. There are currently more than 465 species of sharks known worldwide.

Figure 4: Orders of shark-like fishes according to COMPAGNO (2001); shark orders are shown in numbers 3 to 10 (from top to bottom); the first two correspond to chimaeras and batoids.



The batoids ("flat sharks") are classified into five orders as shown in Figure 5 (four found in the region), 15 families (nine found in the region) and about 62 genera; altogether there are nearly 600 recognised species.

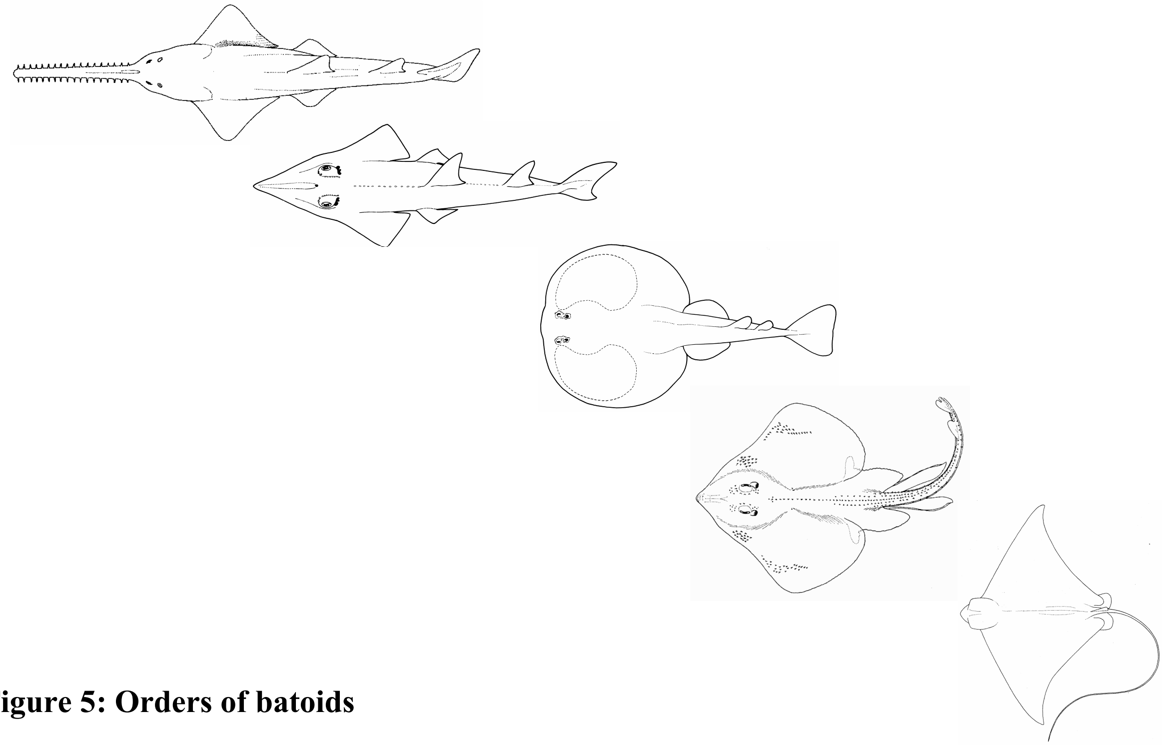


Figure 5: Orders of batoids

In general, it is relatively easy to differentiate between different families or genera of sharks and rays because their general body shape is different (Figure 6). However, sometimes it is very difficult to separate species within the same genus (Figure 7).

Figure 6: Sharks of different orders and families:

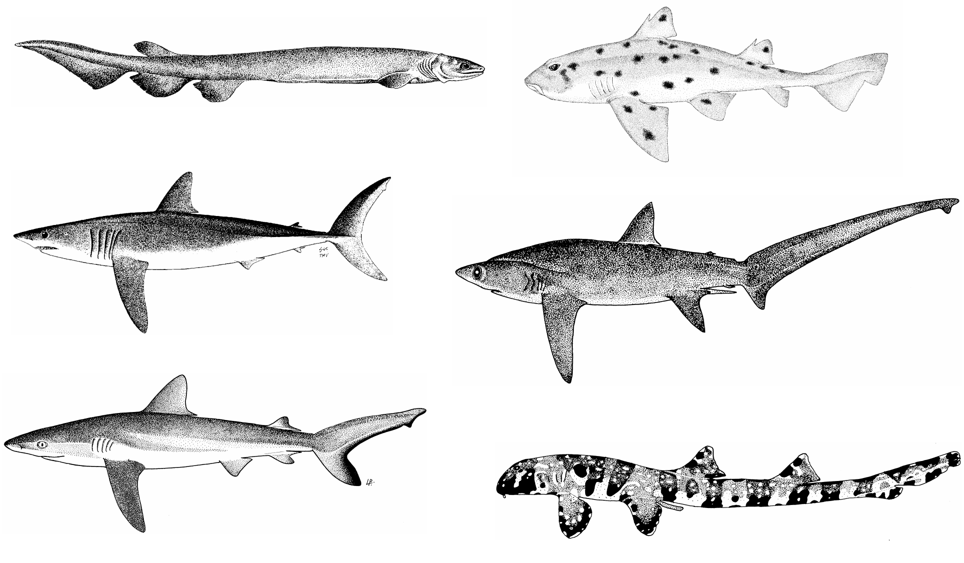
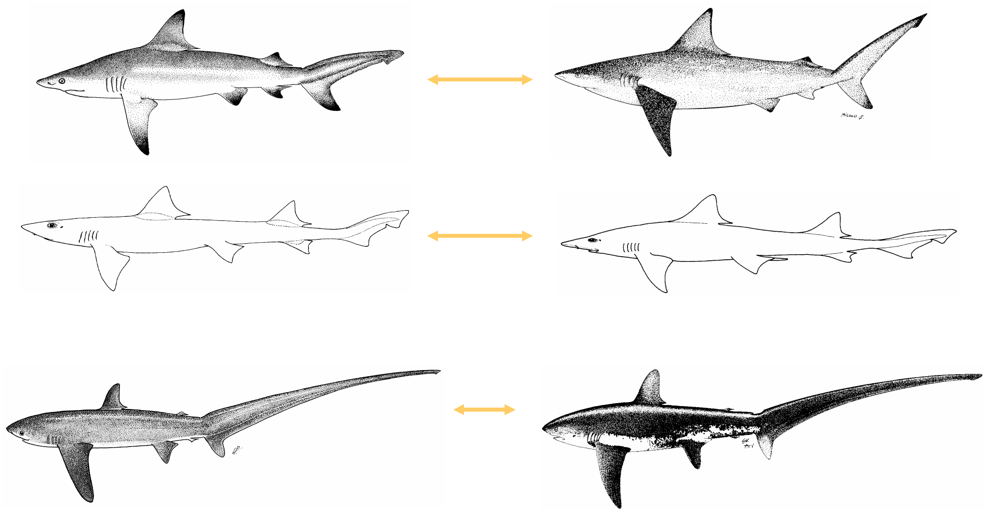


Figure 7: Sharks of the same family or genus:



Characters used in elasmobranch identification

The **most useful** characters used for shark and batoid identification are:

fins:

a) number,

b) size and shape,

c) position,

d) presence/absence of fin spines.

head:

a) shape and proportions of snout in relation to mouth

teeth:

a) shape,

b) number of teeth rows.

body colour and markings

Some of the **secondary** characters useful for identification in sharks and batoids include:

a) number of vertebrae (total, caudal, precaudal, monospondylous, diplospondylous),

b) pattern of dermal denticles coverage inside the roof of the mouth,

c) shape of body dermal denticles.

The best field strategy for the successful identification of sharks and batoids is to do a good literature review before starting. Users should get to know the species likely to be found in the region, their general appearance and the key identification characters of each one.

Once in the field the following steps can be very helpful aids for identification. First, take a photograph of the lateral side, underside of head, and any conspicuous characteristics of each specimen. This allows careful comparison of its characteristics against the keys or descriptions in the literature.

A sample of teeth should be taken. For most shark species, the shape of the teeth can provide a very good identification of the species when used with a photograph of the specimen. Teeth should be taken from the front row of the upper jaw, including the middle and lateral parts of the jaw. If possible, a few teeth should be collected from the lower jaw.

A good set of photographs and a sample of teeth can usually provide enough information to identify a shark species.

Orders of sharks in the PERSGA Region

Heterodontiformes – bullhead sharks

Bullhead sharks are the only group with anal fin and spines on the dorsal fins. They have the mouth in front of the eyes and supraorbital crests.

There is only one family in the region:

a) Heterodontidae –bullhead sharks.

Lamniformes – mackerel sharks and relatives

These sharks have no movable eyelid and an arched mouth that extends behind the eyes. There are three families in the region:

a) Odontaspididae – sandtiger sharks,

b) Alopiidae – thresher sharks,

c) Lamnidae – mackerel sharks.

Orectolobiformes – nurse sharks and whale sharks

The mouth is in front of the eyes but in contrast with the Heterodontiformes, they have no spines on the dorsal fins. The fourth gill opening overlaps the fifth, which is generally reduced in size. The nostrils have barbels.

This order is represented by three families in the region:

a) Stegostomatidae – zebra sharks,

b) Ginglymostomatidae – nurse sharks,

c) Rhincodontidae – whale shark.

Carcharhiniformes – ground sharks and relatives

These sharks have an arched mouth, which extends behind the eyes. A movable eyelid protects the eye. They have a scroll or spiral type intestinal valve. It is the most diverse order in the region, represented by six families:

a) Scyliorhinidae - cat sharks,

b) Proscyllidae – finback catsharks,

c) Triakidae – smoothhounds,

d) Hemigaleidae – weasel sharks,

e) Carcharhinidae – requiem sharks,

f) Sphyrnidae – hammerhead sharks.

Orders of batoid fishes in the PERSGA Region

Pristiformes – sawfishes

These batoids have a shark-like body form, a saw-like elongated snout with strong lateral teeth on each side and gill slits on the underside of the head. There is one family:

a) Pristidae.

Torpediniformes – electric rays and numbfishes

The pectoral fins are expanded and fused with the head and trunk forming an oval disc. The tail is shark-like in shape, without spines. This is the only elasmobranch group with electric organs on the sides of the head (seen through the skin as a pattern of hexagonal markings). There are three families in the region:

a) Torpedinidae – electric rays

b) Narcinidae – numbfishes

c) Narkidae – sleeper rays.

Rhinobatiformes – guitarfishes, wedge-fishes and shark-rays

Batoids in this order have a shark-like body shape, the pectoral fins are expanded and fused with head and trunk; they have two sub-equal and well-separated dorsal fins and no saw-like snout. There are two families in the region:

a) Rhynchobatidae – wedge-fishes,

b) Rhinobatidae – guitarfishes.

Myliobatiformes – stingrays, butterfly rays, eagle rays and mantas

The body is flattened with greatly expanded pectoral fins that are fused with the head and trunk. The tail is whip-like, sometimes with a spine or two. Sometimes there is a single dorsal fin but no caudal fin. This is the most diverse order with five families in the region:

a) Dasyatidae – stingrays,

b) Gymnuridae – butterfly rays,

c) Myliobatidae – eagle rays,

d) Rhinopteridae – cow-nose rays,

e) Mobulidae – mantas and devil rays.

SAMPLING METHODS

The main purpose of fisheries sampling is to gather the information needed for stock assessment of the main species. This includes:

a) estimation of catch composition by species,

b) estimation of size and age structure of the catches by species,

c) establishment of length-weight and other meristic relationships by species (needed for the estimation of total catch for each species),

d) estimation of fishing effort,

e) information on fishing grounds,

f) collection of biological data/samples.

The information from sampling can be entered in the field data log-sheets shown in Figure 8.

The data log-sheet is designed for use in the first stage of a carefully planned shark fisheries programme. Its purpose is to gather meristic and biological information from shark landings. Taking specific measurements for each species will make it possible to measure statistical relationships from the lengths between different parts of the body. The aim is to reach a second stage during which measurements of only one length can be taken. Ideally, this is the length to the second dorsal-fin origin as sharks are often landed without the tail, making it difficult to estimate their total length. The measurement of the length to the origin of the second dorsal fin is also easier to take. During this a second stage, the partial-length measurements are translated into total lengths and then to weight. This allows a better estimation of the live weight for each species in total catches. For some species, this information can be found in the literature. However, for many of the local species these statistical relationships need to be established using detailed first-stage sampling.

Figure 8: Sampling data log sheet for sharks and rays

Sampling Data Log-Sheet for Sharks and Rays

Regional Organization for the Conservation of the Environment of the Red Sea and Gulf of Aden

Name of recorder ______________________

Date ______________________

City/town ______________________

Name of locality or boat ______________________

Type of boat ______________________

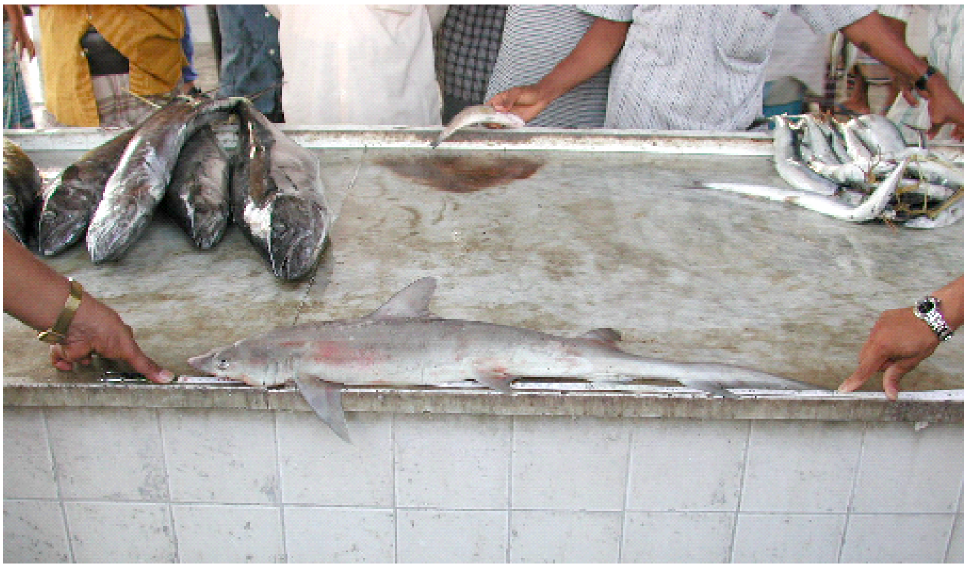
Type and amount of fishing gear ______________________

Number of days fishing ______________________

Approximate fishing grounds ______________________

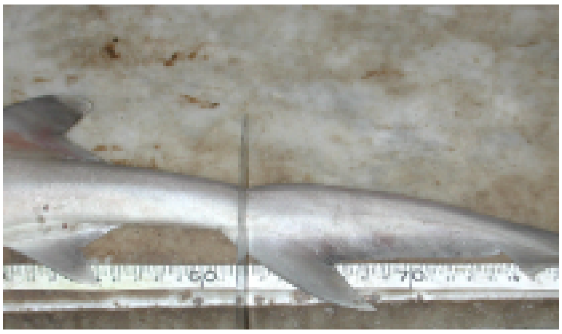
Sample number	**Species name**	Second dorsal-fin length D2L	Pre-caudal length PCL	Fork length FL	**Total length TL**	**Weight W**	Whole (w) or gutted (g)?	**Sex** (m) (f)	**Relative age**: Newborn (N) Young of year (YY) Juvenile (J) Preadult (PA) Adult (A)	**Clasper length**	**Samples taken**	**Observations**

Lengths should be measured with the specimen lying on its belly, starting at the tip of the snout and measuring along a straight flat line parallel to the mid axis of the shark and aligning the upper part of the tail with the main axis as shown below:



Total length

Fork length

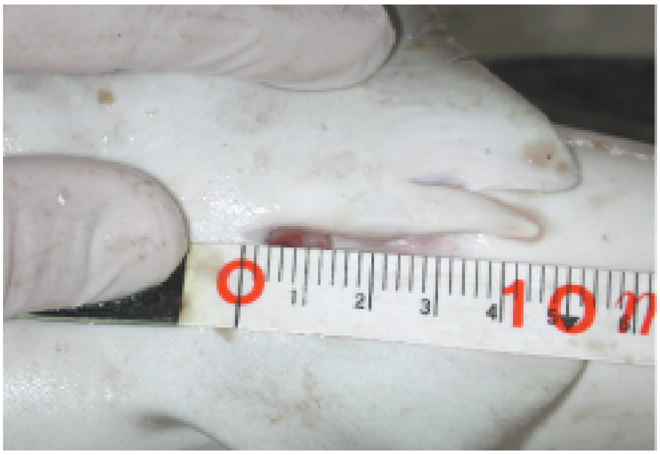


Precaudal length

Length to second dorsal fin

Whenever possible, sharks should be weighted and the claspers of males measured to the nearest millimetre.

Weight



Clasper length (sexual maturity in males)

COURSE 2 – STOCK ASESSMENT OF SHARK AND RAY FISHERY RESOURCES

Objectives

The course objectives were to:

a) train regional fisheries scientists in the theory and practice of modern stock assessment methods for sharks and rays,

b) provide trainees with direct practical experience in the computer-based analysis of data and elaboration of stock assessments using data on elasmobranch fisheries from the literature,

c) increase the technical capacity of regional staff as a starting point for appropriate long-term management of elasmobranch resources.

Course description

The course involved classroom lectures explaining concepts and theory and hands-on practical computer exercises. It included a general introduction to the objectives and practice of stock assessment and management and the interrelationship between them. Different methods used for the assessment of sharks and rays were presented. The contents were designed to provide the trainees with a thorough background knowledge of the methods available for stock assessment of fishery resources, including the advantages and disadvantages of each method.

A package of relevant literature was provided to all the trainees at the beginning of the course and handouts were given at the beginning of each practical session.

Trainees were evaluated based on three written practical reports and a final individual quiz. The practical reports used the standard format of a small scientific report, so that the results of the practical exercises and the contents of the report could be taken into account in the evaluation. The final quiz is appended as Annex III.

Course synopsis

The course sessions were:

First session: 9-10:45 hrs

Morning break: 10:45-11:00 hrs

Second session: 11:00 -12:45 hrs

Lunch break: 12:45-14:00 hrs

Third session: 14:00-15:45 hrs

Afternoon break: 15:45-16:00 hrs

Fourth session: 16:00-18:00 hrs

Course Outline

Day 1

General remarks: course outline, schedule, practical work, organisation, and evaluation

Lecture 1 Introduction: role of stock assessment in fisheries management and the objectives of fisheries management

Lecture 2 Sharks and rays as fishery resources: overview of world fisheries for elasmobranchs - international trends and patterns of exploitation

Lecture 3 Shark biology and its relation to the fragility of fisheries: the diversity of shark life histories - examples of stock collapses

Day 2

Lecture 4 History of shark stock assessment and management: overview of models used for elasmobranch stock assessment - management of real-life shark fisheries (southern Australia, Canada, east coast USA, New Zealand, Mexico, Argentina)

Lecture 5 Simple assessment methods: estimation of mortality - demographic evaluation techniques (life tables)

Practical session 1: calculation of a species' intrinsic rebound potential using the method of Smith et al

Day 3

Lecture 6 Surplus production models: population growth and biomass dynamic models - Schaefer model, Fox model, and Pella-Tomlinson model

Lecture 7 Models and data: fitting models to data and parameter estimation, the importance of data contrast; dangers of the assumption of linearity between catch per unit effort (CPUE) and abundance, early conceptions about shark stock assessment models

Practical session 2: fitting the Schaefer production model to catch and abundance data using Excel computer spreadsheets

Day 4

Lecture 8 Partially age structured models: Deriso-Schnute delay-difference model and yield-per-recruit models

Lecture 9 Models and Data II: introduction to Bayesian estimation

Practical session 3: fitting the delay-difference model to fisheries data in Excel using Bayesian estimators

Day 5

Lecture 10 Age-structured models: virtual population analysis**,** catch-at-age models

Day 6

Final course evaluation (quiz)

LECTURE 1 - THE ROLE OF STOCK ASSESSMENT IN FISHERIES SCIENCE, THE OBJECTIVES OF FISHERIES MANAGEMENT AND OTHER BASIC FISHERIES CONCEPTS

The introductory lecture provided a framework for understanding the role of stock assessment. It reviewed and defined some simple but important concepts essential to the understanding of the objectives of fisheries science. It also discussed the links between stock assessment and fisheries management. Two important questions addressed were:

a) What is the objective of fisheries science?

b) Why are there fisheries scientists and a whole discipline around fisheries?

The answer to the first question is that the ultimate purpose of fisheries science is to enable management (HILBORN & WALTERS, 1992). The purpose of fisheries science is not only to study fish biology, how fish grow, how they move, fishermen's behaviour, how much they catch, how they catch it, or how much money they make, - the ultimate goal is efficient management.

This does not mean that investment in fish biology and stock assessments are not important, but that they are a very important *means to an end*. The relevance of fisheries studies is that the information produced is essential for effective resource management and worldwide conservation.

There are several definitions of the objective of *stock assessment*, all of them more or less compatible. According to SPARRE & VENEMA (1992), the basic purpose of fish stock assessment is "to provide advice on the optimum exploitation of aquatic living resources". However, the best definition probably comes from HILBORN & WALTERS (1992): "Stock assessment involves the use of statistical and mathematical analyses to make quantitative predictions about the reactions of fish populations to alternative management choices". The last definition is especially relevant because it explicitly says two important things:

a) *quantitative predictions* are needed in the assessment process

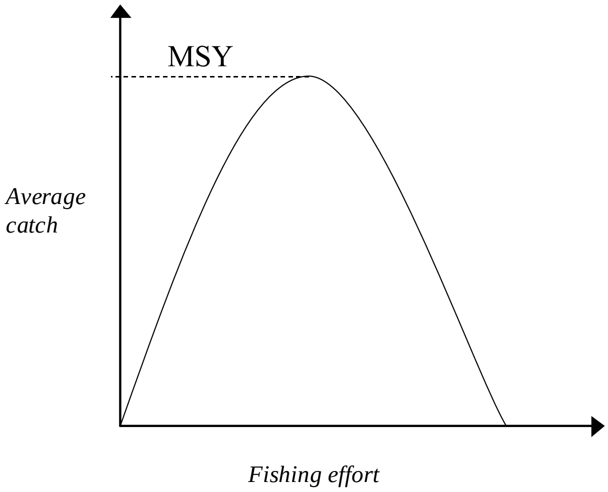
b) the objective is to provide *advice for management*

Stock assessment must be a *quantitative* discipline. Computer analysis and numerical methods are becoming more rigorous and useful. A *system for management* should be in place before making quantitative predictions using stock assessments; otherwise the work will not translate into management actions.

An important question is "what is the purpose of *fisheries management*?" SPARRE & VENEMA (1992) define it as "*the search for the exploitation level which in the long run gives the maximum yield in weight from a fishery*". According to HILBORN & WALTERS (1992), the most widely accepted fundamental purpose of fisheries management is to *ensure the sustainable production over time from fish stocks*.

The traditional fisheries model says that as effort increases, catch will increase up to a maximum and then will decrease. This leads to the concept of maximum sustainable yield (MSY) which has been the Holy Grail of fisheries. See Figure 9.

Figure 9: Graph showing maximum sustainable yield (MSY)



The specific shape of the above curve does not matter. The important principle always holds - zero effort means zero catch and too much effort leads to small or almost zero catch. In theory there should also be a maximum catch at the top of the curve – the MSY.

The problem with this concept is that natural systems have a lot of random variability from:

a) fish growth and reproduction,

b) environmental effects (abiotic and biotic) on biological and ecological processes,

c) the behaviour of fishermen.

In practice, real data will always reflect this variability as 'noise'. The danger of focusing stock assessment solely on finding MSY and the associated optimum effort ($\mathbf{f_{opt}}$) is that we can never be sure when the MSY is reached. Attempts at caution by developing a fishery at a very slow pace will not guarantee that we will not overexploit a stock or waste opportunities. An excellent example of the effects of variability in fisheries data and the uncertainty about MSY comes from studies on Atlantic yellowfin tuna (*Thunnus albacares*) (HILBORN & WALTERS 1992). In the mid-1970s the MSY level was calculated to be about 50,000 t (metric tonnes). The fishery continued to grow and a second analysis 10 years later suggested an MSY of more than 100,000 t, clearly indicating that the first assessment was a 'false' MSY. The question remaining was if the second assessment was also an underestimate.

The real problem in most cases from real fisheries is that (especially with noisy data,) we have to go beyond MSY to confirm it has been detected. This effectively means that we can never prevent over-exploitation even in the best case. This is an important principle identified by HILBORN & WALTERS (1992): *"you cannot determine the potential yield from fish stocks without overexploiting them"*. The secret is not to overexploit the stock beyond recovery in an effort to find MSY. An additional practical problem is that once fisheries have actually passed the MSY point and gone into the overexploitation phase of the fishery more problems arise. In this case, the fishery is already in the over-capacity side of the curve. This leads to another sad but important principle stressed by HILBORN & WALTERS (1992): *"The hardest thing to do in fisheries management is to reduce fishing pressure"*. In an ideal situation a new fishery should start with all the mechanisms in place to ensure:

a) detection of MSY quickly (i.e. a good monitoring and data acquisition system should be in place),

b) mechanisms to reduce effort effectively without detrimental effects (high taxes that can be later used to buy back boats or compensate for loss catch per boat).

MSY is a theoretical concept that is most useful as a *general concept* to guide our management, *not as the aim* of fisheries assessment. Fisheries assessment is really about *understanding the dynamics of fisheries* to make accurate predictions about fish and fishermen.

The explicit statement of clearly defined objectives for fisheries management is extremely important; it is unfortunately often overlooked. The MSY concept is a benchmark, but most importantly it is a *biological* concept. However, in the real world fisheries should preferably be managed through actions that promote economic and social well being of the fishermen and associated industries. Unfortunately, it is often not possible to achieve all these biological, economic and social objectives simultaneously. In fact although MSY can be seen as the *overall and general purpose of management*, there are other more *specific objectives* of fisheries management that are not necessarily obtaining maximum yield in the long term. More precisely, fisheries management objectives can be broken down into at least four categories:

a) biological,

b) economic,

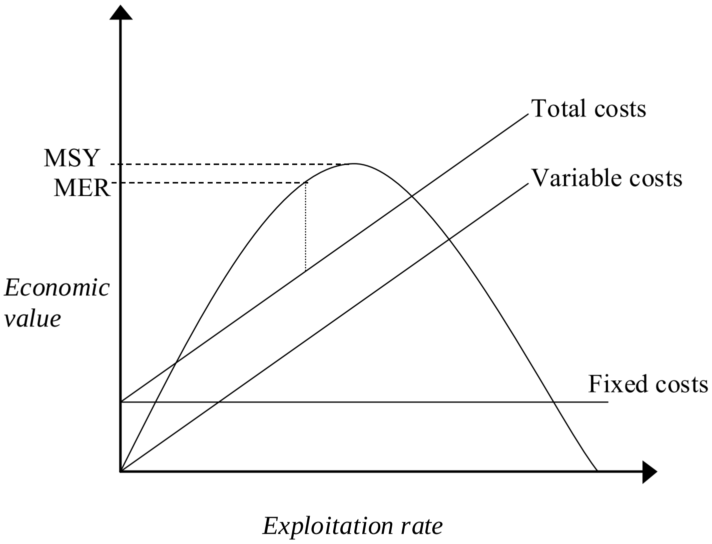
c) social,

d) recreational.

Biological objectives – By default this is MSY, explained above. The standard indicator of biological yield will be annual weight or number of fish caught.

Economic objectives - In economic terms, to obtain the maximum amount of fish (MSY) is not the main objective. Fisheries are an economic activity and thus should aim for economic rent; that is the total revenue minus the total costs. The concept of maximum economic rent (MER) is an economic analogue of MSY. However, as shown in Figure 10 below, the point of the curve defining MER will by definition always be at a lower effort level than MSY. It is clear from this that it is impossible to attain MSY and MER at the same time.

Figure 10: Graph showing MSY and MER



Recreational objectives – In many parts of the world, interests in fish stocks have to be shared between commercial fisheries and recreational fisheries. For recreational purposes, both the catch and the effort (successful fishing trips) might be important objectives. The total number of fish available to be fished can be also very important, but in the case of trophy fish, the size of the fish will also be relevant. In such as case it might be an objective to have a few large fish rather than many small ones. The standard indicators for recreational fisheries include estimated value of recreational effort (dollars per day, times and days fished) and the numbers and size of the recreational catch.

Social objectives – Fishing is the most important source of employment in remote villages in many parts of the world. In such situations, having a large number of not-so rich fishermen might be more desirable than having a few very rich ones. Also, it is often important to preserve community structure and traditional lifestyles. Communities that have been fishing for a hundred years or more should not just disappear. From the social point of view, the total number of jobs related to the fishing activity is often the standard indicator, as are the distribution of income and the maintenance of traditional lifestyles.

Very often the different objectives of fisheries management are conflicting and difficult choices have to be faced by managers. For this very reason it is imperative that a healthy and open discussion of the overall objectives of management for each fishery is held as early as possible. Only through clearly specified objectives can fisheries management and stock assessment work hand in hand.

Managers have to make *quantitative decisions* about how many fish can be caught, the number of boats that will be allowed to enter a fishery, the minimum size of a fish or a gillnet mesh that should be allowed etc. They also have to make decisions about how much they should spend in research, enforcement of regulations, etc. Within this context, fisheries *assessment* is about giving *advice* on the status of the resource and the likely results of alternative measures. Once this is done, the choice of action to be taken remains, (usually a given amount of fish or quota, different combinations of effort and number and size of boats), usually made on economic and social grounds.

HILBORN & WALTERS (1992) identified the following important principles:

a) fisheries management is about making *choices*,

b) it is not possible to choose without *comparing* choices,

c) in order to make comparisons we need to make *predictions*,

d) predictions cannot be done without a *model*,

e) the choice of fisheries scientists is not *whether* to model but *how* to model.

This leads us directly to the next topic: what is a model? In general terms, a model is simply a representation of reality. In science, models often take the form of equations or sets of equations. Take for example the following concept turned into a model:

Velocity (speed) = distance/time $v = d/t$

Models are needed because empirical, intuitive decisions are mostly always wrong. Example: intuition tells us that complicated and detailed models are always better than simple models. However, LUDWIG et al. (1988) showed that simple models usually perform better because they require estimation of a smaller number of parameters.

LECTURE 2 - SHARKS AND RAYS AS FISHERY RESOURCES: OVERVIEW OF WORLD FISHERIES FOR ELASMOBRANCHS; INTERNATIONAL TRENDS AND PATTERNS OF EXPLOITATION

A summary of the lecture is presented with illustrations.

World elasmobranch fisheries have increased steadily since records began in the 1950s to a current level of over 800,000 t per year. This represents less than 1 % of the total fisheries catches of the world (all species). Historically, the most important elasmobranch catches in terms of average catch per year have been taken in the northwest Pacific, western Indian, northeast Atlantic and western central Pacific oceans. However, if an index of relative production (IRP) of elasmobranchs is calculated taking the size of each region into account, the most productive regions, in order of importance are: the NE Atlantic, the NW Pacific and the western Indian oceans. The IRP can be used to produce a map allowing us to classify regions according to the relative production of elasmobranchs. Any increases in yield of sharks and rays are likely to come from those regions with the lowest IRP. In theory, these are the areas where stocks should be less exploited.

Globally, shark and ray production was almost equally shared between developed and developing countries but, over the last 30 years, most of the catches have been taken by the developing countries. The implications of this are that, given their more limited resources, it will be more difficult to establish adequate management systems for elasmobranch fisheries without the financial help of the developed world. At least 23 countries have taken elasmobranch catches of more than 10,000 t per year for the last five years. These are the most important elasmobranch fishing nations. The list is lead by Indonesia, India, Taiwan, Pakistan and Mexico. Two ways to look at elasmobranch catches at the global level are:

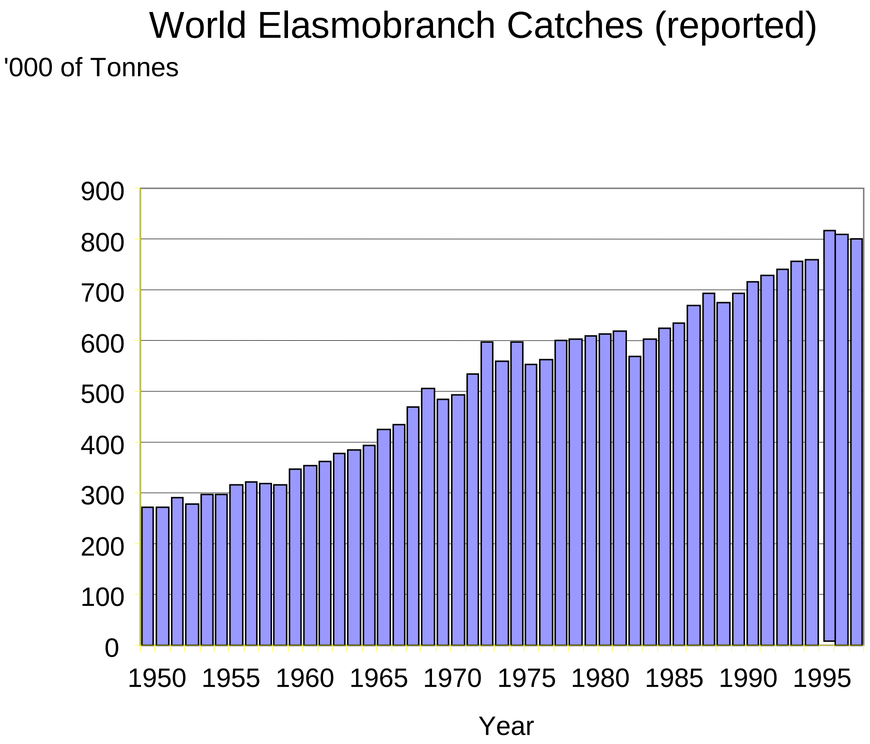
a) to analyse the average yearly yield of each nation,

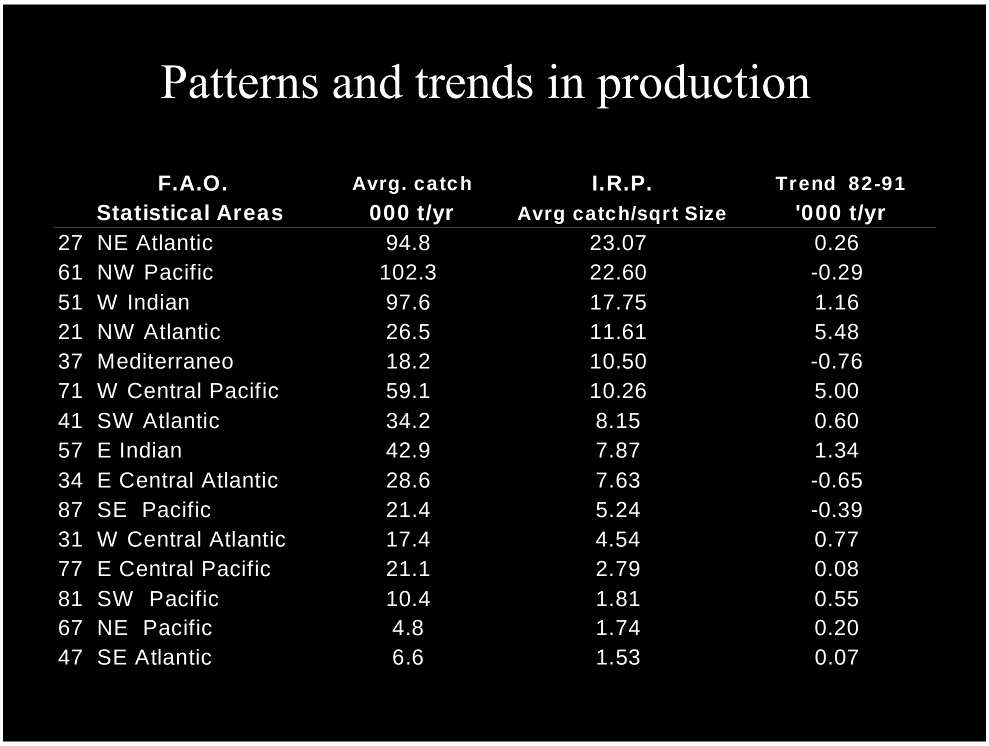
b) to look at the importance of the elasmobranch catch of each nation relative to their overall fisheries production.

The two approaches offer us very different perspectives on what ‘important shark fishing nation’ means.

While the global catch of sharks and rays seems to keep growing, the analysis of historical records of national elasmobranch catches show that possible stock collapses can be identified. In many cases, fisheries move from one overexploited stock to a relatively unexploited stock, depleting one after the other. Hence the need to monitor and manage these vulnerable resources before it is too late. The shark and ray fisheries in the Red Sea and Gulf of Aden region are relatively minor, although Yemeni fisheries may prove to be important at the global level, especially if more accurate statistics become available.

Illustrations from the lecture





Patterns and trends in production

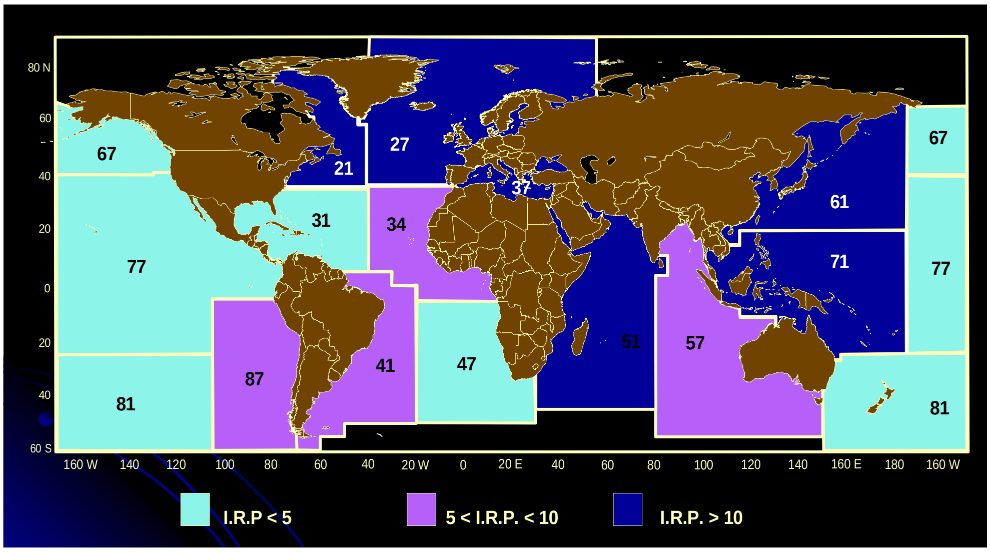
F.A.O. Statistical Areas	Avrg. catch 000 t/yr	I.R.P. Avrg catch/sqrt Size	Trend 82-91 '000 t/yr
27 NE Atlantic	94.8	23.07	0.26
61 NW Pacific	102.3	22.60	-0.29
51 W Indian	97.6	17.75	1.16
21 NW Atlantic	26.5	11.61	5.48
37 Mediterraneo	18.2	10.50	-0.76
71 W Central Pacific	59.1	10.26	5.00
41 SW Atlantic	34.2	8.15	0.60
57 E Indian	42.9	7.87	1.34
34 E Central Atlantic	28.6	7.63	-0.65
87 SE Pacific	21.4	5.24	-0.39
31 W Central Atlantic	17.4	4.54	0.77
77 E Central Pacific	21.1	2.79	0.08
81 SW Pacific	10.4	1.81	0.55
67 NE Pacific	4.8	1.74	0.20
47 SE Atlantic	6.6	1.53	0.07

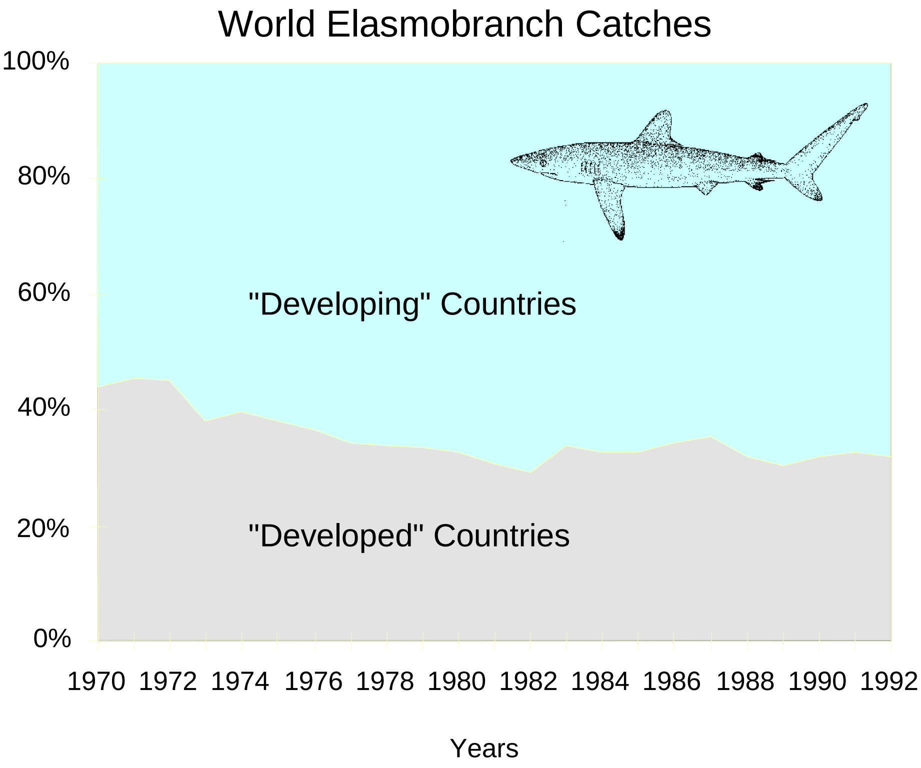
Catches by FAO Statistical Areas

Index of Relative Production

$$IRP = \frac{Average Catch 1966-1991}{\sqrt{Surface Area}}$$

Numbers represent the FAO codes for statistical Fishing Areas

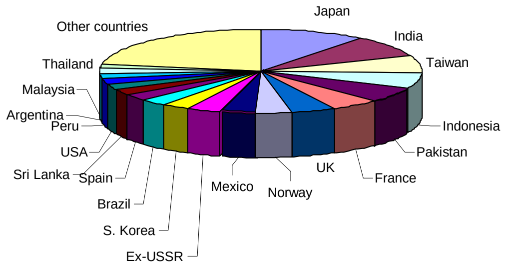




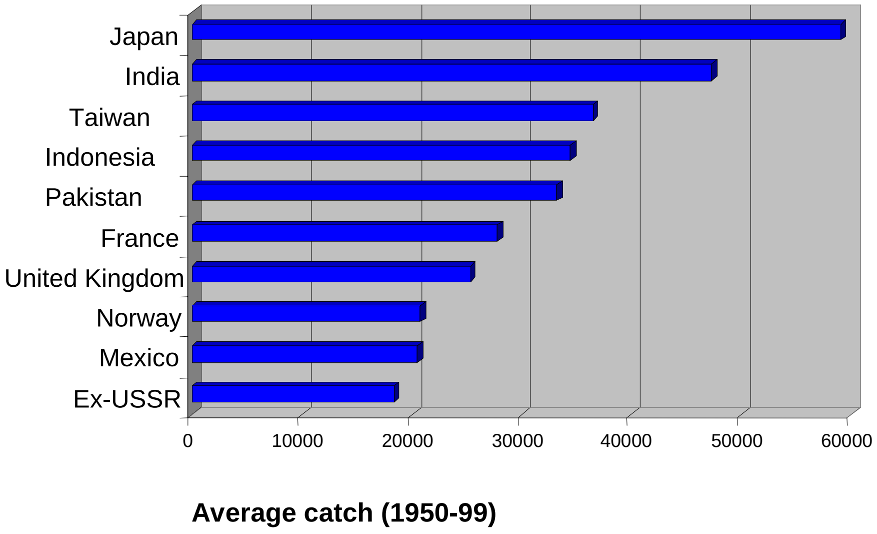
Main Producers of Elasmobranchs

- Indonesia
- India
- Taiwan
- Pakistan
- Mexico
- USA
- Japan
- Spain
- France
- Sri Lanka
- Argentina
- United Kingdom
- Malaysia
- Brazil
- Korea
- Republic of Thailand
- Portugal
- New Zealand
- Peru
- Italy
- Australia
- Maldives
- Canada

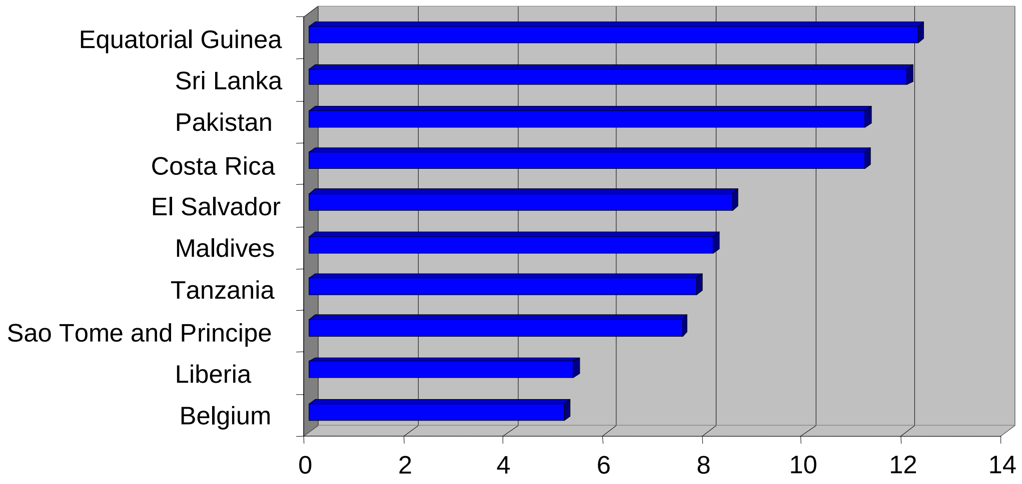
Share of Elasmobranch Catch

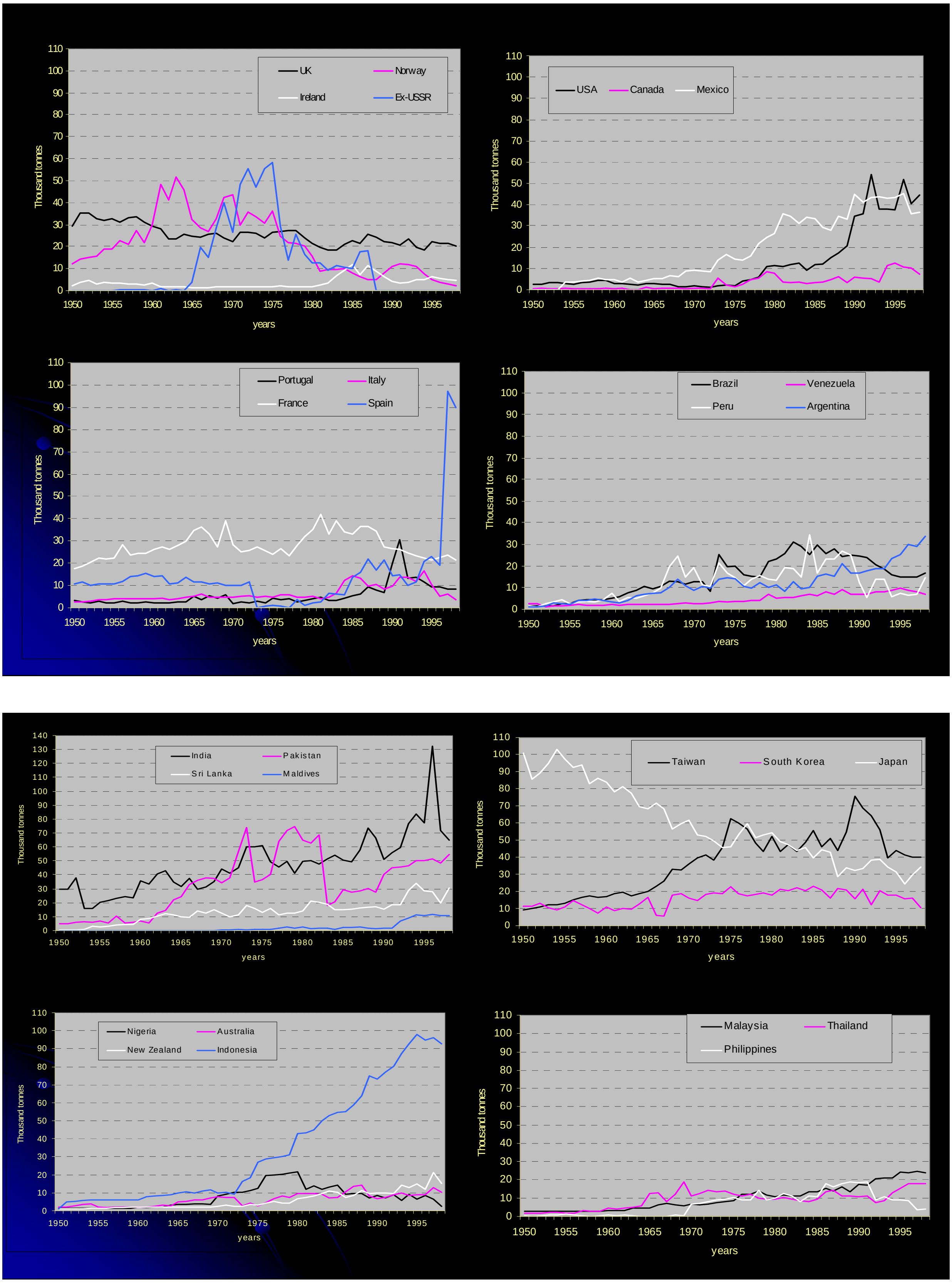


Top 10 Shark-fishing countries



Sharks and rays as percentage of total catch (1989-98)



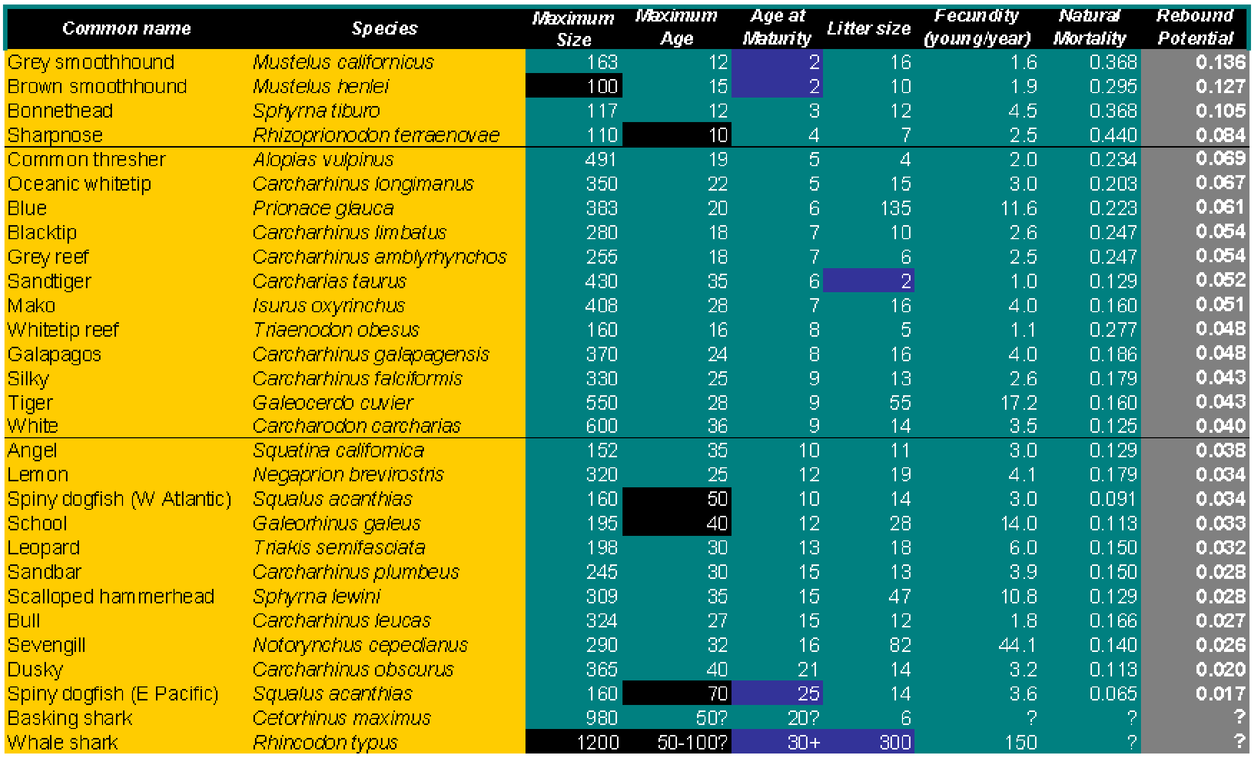


Catch by weight (thousand tonnes), 1950-2000

LECTURE 3 - SHARK BIOLOGY AND ITS RELATION TO THE FRAGILITY OF FISHERIES: THE DIVERSITY OF SHARK LIFE HISTORIES AND EXAMPLES OF STOCK COLLAPSES

This lecture reviewed the main taxonomic divisions and the biological characteristics of elasmobranchs. It focused on the relevance of life history traits to the potential for their exploitation. A detailed and illustrated review of reproduction was given and the reproductive modes most commonly observed in each taxon were outlined. This was followed by an analysis of the most relevant life history traits of 25 species of sharks (SMITH et al. 1998). The great diversity of life history characteristics among sharks was illustrated by comparing the differences in maximum size, maximum age, age of first sexual maturity, litter size and natural mortality of each species, as shown in the table below.

This was followed by an explanation of the basic processes regulating changes in the size of a natural population and the close relationship between some life history traits and the size and growth of a population. The relative diversity of life histories of sharks was exemplified by linking the life history characteristics to the *rebound potential* as calculated by SMITH et al. (1998). The rebound potential is a modified calculation of the intrinsic rate of increase in a population from demographic analysis. The intrinsic rate of increase of some important bony fish species was compared to the rebound potential of sharks. It was shown how most elasmobranchs are relatively less productive species than bony fishes. The lecture concluded with a review of some of the best-documented cases of decline in elasmobranch fisheries soon after high exploitation. The possible reasons behind each of the collapses were discussed.



Common name	Species	Maximum Size	Maximum Age	Age at Maturity	Litter size	Fecundity (young/year)	Natural Mortality	Rebound Potential
Grey smoothhound	*Mustelus californicus*	163	12	2	16	1.6	0.368	**0.136**
Brown smoothhound	*Mustelus henlei*	100	15	2	10	1.9	0.295	**0.127**
Bonnethead	*Sphyrna tiburo*	117	12	3	12	4.5	0.368	**0.105**
Sharpnose	*Rhizoprionodon terraenovae*	110	10	4	7	2.5	0.440	**0.084**
Common thresher	*Alopias vulpinus*	491	19	5	4	2.0	0.234	**0.069**
Oceanic whitetip	*Carcharhinus longimanus*	350	22	5	15	3.0	0.203	**0.067**
Blue	*Prionace glauca*	383	20	6	135	11.6	0.223	**0.061**
Blacktip	*Carcharhinus limbatus*	280	18	7	10	2.6	0.247	**0.054**
Grey reef	*Carcharhinus amblyrhynchos*	255	18	7	6	2.5	0.247	**0.054**
Sandtiger	*Carcharias taurus*	430	35	6	2	1.0	0.129	**0.052**
Mako	*Isurus oxyrinchus*	408	28	7	16	4.0	0.160	**0.051**
Whitetip reef	*Triaenodon obesus*	160	16	8	5	1.1	0.277	**0.048**
Galapagos	*Carcharhinus galapagensis*	370	24	8	16	4.0	0.186	**0.048**
Silky	*Carcharhinus falciformis*	330	25	9	13	2.6	0.179	**0.043**
Tiger	*Galeocerdo cuvier*	550	28	9	55	17.2	0.160	**0.043**
White	*Carcharodon carcharias*	600	36	9	14	3.5	0.125	**0.040**
Angel	*Squatina californica*	152	35	10	11	3.0	0.129	**0.038**
Lemon	*Negaprion brevirostris*	320	25	12	19	4.1	0.179	**0.034**
Spiny dogfish (W Atlantic)	*Squalus acanthias*	160	50	10	14	3.0	0.091	**0.034**
School	*Galeorhinus galeus*	195	40	12	28	14.0	0.113	**0.033**
Leopard	*Triakis semifasciata*	198	30	13	18	6.0	0.150	**0.032**
Sandbar	*Carcharhinus plumbeus*	245	30	15	13	3.9	0.150	**0.028**
Scalloped hammerhead	*Sphyrna lewini*	309	35	15	47	10.8	0.129	**0.028**
Bull	*Carcharhinus leucas*	324	27	15	12	1.8	0.166	**0.027**
Sevengill	*Notorynchus cepedianus*	290	32	16	82	44.1	0.140	**0.026**
Dusky	*Carcharhinus obscurus*	365	40	21	14	3.2	0.113	**0.020**
Spiny dogfish (E Pacific)	*Squalus acanthias*	160	70	25	14	3.6	0.065	**0.017**
Basking shark	*Cetorhinus maximus*	980	50?	20?	6	?	?	**?**
Whale shark	*Rhincodon typus*	1200	50-100?	30+	300	150	?	**?**

(© CSIRO 1998; modified with permission of CSIRO Publishing, from *Marine and Freshwater Research* 49: 663-678 (Smith, S.E. Au, D.W. & C Show. Intrinsic rebound potentials of 26 species of Pacific sharks).

Variety in Reproductive Strategies

Viviparity – with placenta

LECTURE 4 - HISTORY OF SHARK STOCK ASSESSMENT AND MANAGEMENT: OVERVIEW OF MODELS USED FOR ELASMOBRANCH STOCK ASSESSMENT AND EXAMPLES OF THE MANAGEMENT OF REAL-LIFE SHARK FISHERIES

This lecture provided an outline of stock assessment models emphasising those that can or have been used for elasmobranch fisheries. The review included brief details of the characteristics of each method. Further details of the most important stock assessment methods were provided in the following lectures.

In Keith Brander's method and equation (BRANDER 1981), for the mature part of a stock to be in equilibrium (to simplify, only females are usually considered) the mortality of adults (**Z_m**) should equal the net rate of recruitment of mature fish to the population (**R_m**):

$$Z_m = R_m$$

Recruitment (**R_m**) is equal to the number of eggs developing into females (assuming half will develop into females) multiplied by the survival from hatching to maturity $e^{-Zi\ tm}$ (assuming that Z_i occurs evenly through the years needed to reach maturity):

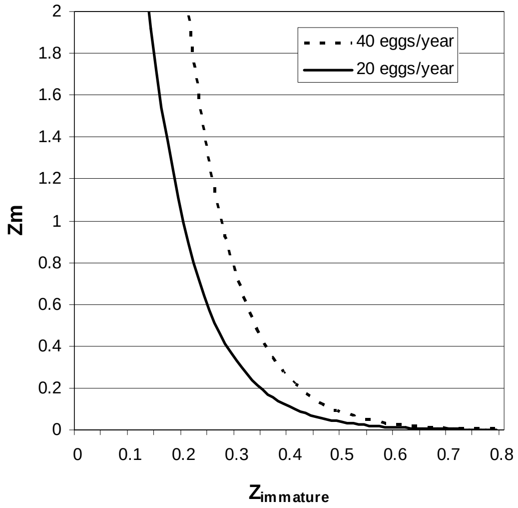
$$R_m = (Eggs/2)\ e^{-Zi\ tm}$$ [1]

In other words, for the population to remain in equilibrium (constant number of fish or constant total biomass through time) the following condition has to be fulfilled:

$$Z_m = (Eggs/2)\ e^{-Zi\ tm}$$

This is Brander's equation; substituting different values of **Z_i** in the previous equation to obtain the corresponding equilibrium **Z_m**, we can calculate the curves seen in Figure 11.

Figure 11: Relationship between mortality from birth to maturity and adult mortality



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[1] e is the well known mathematical constant 2.7183…
tm is time to maturity
Zi is mortality of the immature stock

Mortality values to the right of each curve would eventually drive the adult population to collapse. Figure 11 shows how species with higher fecundity (40 eggs per year in this example) can withstand a higher total mortality.

It is necessary to know the age of maturity and the fecundity of the species in order to calculate the curves. The next step is to determine the actual values of total mortality for the immature and mature stock ($\mathbf{Z_i}$ or $\mathbf{Z_m}$) in question. If the values are to the right of the corresponding curve, management should attempt to reduce total mortality towards an equilibrium level. Catch curves could be used to estimate the level of total mortality for each part of the stock. If catch curves can be calculated then it is usually possible to do a more thorough stock assessment as shown below.

The present method was used by Keith Brander to demonstrate why common rays *Raja batis* were virtually wiped out from the Irish Sea and to compare the 'resilience' of other ray species for exploitation. This method is only useful as a reference point and has never been adopted for the management of a real elasmobranch fishery.

The main limitations of this model are:

a) it does not provide direct management advice in the form of an appropriate catch or effort level,

b) it is not a dynamic model (considering changes in time), but offers only a stationary view, thus processes like density-dependent compensation cannot be included.

Density-dependent compensation is a change in any fundamental process of the population that is directly related to the abundance level of the stock. In reality, most biological processes are density-dependent, especially mortality and recruitment (which is a consequence of pre-recruit mortality). Other processes such as body growth, population growth and fecundity are often density-dependent as well.

Life tables & intrinsic rebound potential

Life tables and Leslie matrix approaches are methods that also allow us to estimate demographic parameters of populations, most importantly the rate of population growth. They are analyses of the demographic characteristics of a population in terms of survival and fecundity of each age class, i.e. a life table is a schedule of the survival and fecundity of the population that allows us to calculate reference parameters of population growth. The most important parameter that we can estimate is the observed rate of increase. This is not exactly the same as **r** (intrinsic rate of increase) of the logistic growth equation, but is a very close estimate of it. (**r** is influenced by natural survival, natality [birthrate] and body growth [when used for biomass models], thus the life table **r** lacks the body growth effect). This method has been used to estimate the intrinsic growth rate of populations of elasmobranchs. Scientists have later used this estimate of **r** in stock production models. Life tables have also been used to demonstrate the relative potential of different species for exploitation. Leslie matrix methods are a mathematically elegant way to express the same processes of the life table approach using matrix techniques.

Some examples of the application of life tables or Leslie matrix approaches to elasmobranchs are:

a) CORTES (1995) for sharpnose shark,

b) CORTES & PARSONS (1996) and MARQUEZ et al. (1998) for Atlantic sharpnose shark,

c) HOFF (1990), and SMINKEY & MUSICK (1996) for sandbar sharks,

d) CALLIET (1992) for leopard sharks,

e) CALLIET et al. (1992) for California angel sharks,

f) MCALLISTER et al. (1998) for sandbar, blacktip and multispecies carcharhinid sharks.

The main limitations of demographic models are the same as in the previous model, they:

a) are static approaches offering a 'snap-shot' of the populations,

b) are unable to provide dynamic *predictions* on what will happen if we fish more or less,

c) usually do not include density-dependent processes (or include them in a very rudimentary way,

d) do not provide any direct advice on how to set management measures.

A recent modification of life table approaches developed by SMITH et al. (1998), shown below, includes some level of density-dependence and allows for estimation of the 'rebound potential' of a population. This is a step forward from classical demographic models but in terms of fisheries stock assessment and management it is still a very limited approach. The predominant use of life tables and modifications of them is to compare the exploitation potential of different populations.

Yield per recruit models

These models, first developed by BEVERTON & HOLT (1957), provide a steady-state (static) view of the population (described in MEGREY & WESPESTAD 1988). They have been used for stock assessment of school sharks by GRANT et al. (1979), for leopard sharks by SMITH & ABRAMSON (1990), and for silky sharks by BONFIL (1990). The calculation of yield per recruit requires the following information or data:

a) at least two mortality rates (**Z** total mortality; M natural mortality; or **F** fishing mortality [F = Z-M]),

b) the parameter **K** (the von Bertalanffy growth coefficient) of the von Bertalanffy growth model (VBGM),

c) the age of first entry of fish to the fishery,

d) the age of recruitment,

e) the maximum age in the stock.

However, they are not used for the management of any elasmobranch species.

The yield per recruit method allows us to calculate the relative biomass (divided by recruitment) that we can extract from a stock given the level of effort (fishing mortality F) and the age of entry to the fishery. Its use is limited to tell us if the fishery is catching fish too early or too late and if the level of fishing mortality is adequate or not. This method is a step forward because it tells us if we are exploiting fish at the right age and if we are fishing them at the right intensity, this can translate into direct management recommendations. Advice can be given on the best 'age of entry' to the fishery and the appropriate 'level of fishing effort'. However, the method provides no assessment of the absolute biomass of the stock, and only limited advice on management actions. Similar to life tables, the disadvantages of this method are that it is static and not dynamic, and it does not incorporate density dependent processes like stock recruitment relationships.

Using the yield per recruit (Y/R) method alone can be quite dangerous as demonstrated by GRANT et al. (1979). They showed that the suggested 10-fold increases in fishing mortality from their Y/R assessments were bad advice. Only a 2-fold increase could already have been reducing the reproductive stock to less than half its original numbers. The main problem of the Y/R analysis is that a poor estimation of growth or mortality can influence all the conclusions very strongly and the stock could be jeopardised.

Surplus Production Models

These models are among the simplest and most widely used for stock assessment. They are easy to use because they usually require only two or three types of data:

a) time series of total catch,

b) effort,

c) if possible an independent index of abundance.

They are very flexible and have different variations, the Schaefer, the Fox, and the Pella-Tomlinson models are some of the best known. They are discussed in more detail in Lecture 6.

Surplus production assumes that:

Next biomass = last biomass + recruitment + body growth – catch – natural mortality

If there is no catch then…

Next biomass = last biomass + production – natural mortality

And

Surplus production = production – natural mortality

Thus

New biomass = old biomass + surplus production – catch

As shown in detail later in this report, these models can be used to estimate the level of depletion of the population, MSY and the optimal fishing effort (**f_{opt}**). Most importantly we can make *projections* about the population under several management scenarios (quotas or efforts) and evaluate their benefits. This is possible because surplus production models explicitly incorporate the time variable. Thus they are *dynamic* models that can be used to make *predictions*. The simplicity of these models is an advantage. A disadvantage is the lack of reality in that they do not include age structure of the population. They assume that all the processes occurring in a population can be captured by the simple equations described above and ignore the population size, age structure, and the dynamics of different parts of the population.

Forty years ago there was a general view that the assumptions of the models and the biology of elasmobranchs were incompatible. However, they are now widely accepted as applicable but not necessarily recommended as the best (see lecture 7). They have been used in the multi-species shark fishery of the east coast of the USA (OTTO et al. 1977, ANDERSON 1980, MCALLISTER AND PIKITCH 1998), for the kitefin shark fishery in Portugal (SILVA 1987) and in the Australian fishery for school and gummy sharks (XIAO 1995, WALKER 1999).

Partially age-structured models: the delay-difference model

The delay-difference model of DERISO (1980) is a smart simplification that allows the inclusion of biological information e.g. age structure, recruitment, natural and fishing mortality and growth to be taken into account in a simple format. It is an intermediate between the very simple surplus-production models that ignore individual biological processes like recruitment and individual growth, and the more sophisticated and data-demanding age-structured models.

The delay-difference model is biologically more realistic (detailed) but can be simplified to use only data on catch, effort and an index of abundance as in surplus production models. However, the delay-difference model also requires knowledge of the increase in individual weight of the species and an estimate of natural mortality. A complete description of the method is given in Lecture 8.

This model has not been used for the assessment of shark fisheries very often but Monte Carlo simulations performed by BONFIL (1996) showed that the delay-difference model could be employed to estimate stock status of shark-like fishes and performed better than surplus production models. This model was also used as part of the assessment of the school shark and gummy shark fisheries of Australia (WALKER 1999).

Age-structured models

These methods are based on catch-at-age data i.e. they require the catch to be broken down into age groups. These methods are more sophisticated, detailed, and realistic than previously reviewed models. Age-structured models require considerable detailed data, which is often expensive to obtain.

HILBORN & WALTERS (1992) classified age-structured models into two groups:

a) Virtual Population Analysis or VPA,

b) statistical catch-at-age analysis - CAGEAN methods.

VPA is also known as cohort analysis. These methods are recursive[2] algorithms that calculate stock size based on the composition of age-classes found in catches. These methods estimate the magnitude of fishing mortality, the numbers at each age for the stock within the catch and an estimate of natural mortality 'M'.

VPA does the calculations without having a specific underlying statistical assumption. It does not explicitly consider recruitment, as calculations usually stop at the age of recruitment to the fishery. In contrast, the more sophisticated CAGEAN methods depend on formal models to integrate various types of data in a statistical framework. Thus, data on S/R (stock-recruitment) relationships, CPUE time series, biomass time series and others can be integrated into a very powerful analysis. The stock synthesis method of METHOT (1989) is one of the best examples of these sophisticated CAGEAN models.

A fundamental part of age-structured models is the concept of *cohorts*. A cohort comprises all the individual fish born in the same year. An example of a human cohort is all the persons that were born in 1960. The cohort of 1960 can be followed through time by looking at individuals that are age 1 in 1961, age 2 in 1962 and so on. The size of the cohort 1960 in the year 2002 is all the individuals that have survived from 1960 up to 2002.

VPA and CAGEAN methods calculate the number of fish alive in each cohort, following cohorts through time. These methods are also known as cohort analysis because each cohort is treated separately.

These methods are based on the following equation:

N alive at beginning of next year = (N alive at beginning of this year) – (catch this year) – (natural mortality this year)

In VPA, recruitment is not considered because we are analysing only a single cohort.

We can change the above equation to:

N alive at beginning of this year = (N alive at beginning of next year) + (catch this year) + (natural mortality this year)

Assuming that we know the natural mortality **M** and that at some age there are no more fish alive (i.e. that all fish die after age **X**) we can calculate the number of fish alive each year, starting with the oldest and moving backwards to the youngest. This is the basis of both of these methods. They are discussed in more detail in Lecture 10.

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[2] Recursive – of, relating to, or constituting a procedure that can repeat itself indefinitely or until a specified condition is met.

Management of real-life fisheries

The preceding concepts are put into context by presenting an overview of the assessment methods and corresponding management regimes of six elasmobranch fisheries from the literature. See Table 3.

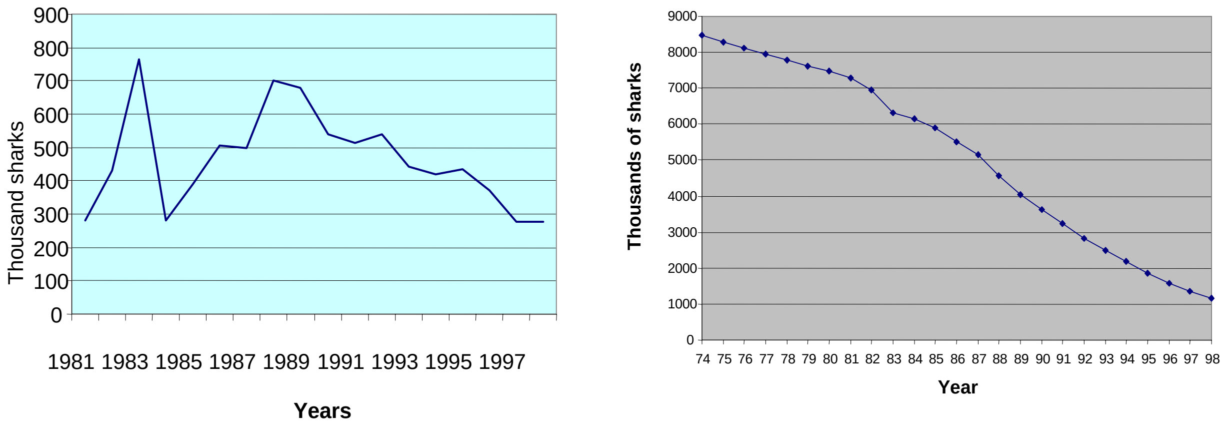
The case of the US Atlantic large coastal shark fishery was analysed briefly as an example of the often complicated aspects of real fisheries stock assessment. The graphs in Figure 12 illustrate:

a) the evolution of the catches,

b) the conflicting information on abundance indices that was available for the assessment (each time series represents a different survey or sector of the fishery which often show different trends, most are incomplete and limited in geographic coverage),

c) the best estimate of the trends in the overall population as obtained by using surplus production models with Bayesian estimators.

Figure 12: Plots from the Atlantic coastal shark fishery data



Above: the evolution of the catches, 1981 – 1997 in US Atlantic shark fishery

Upper right: US fishery population trajectory

Opposite: conflicting CPUE information

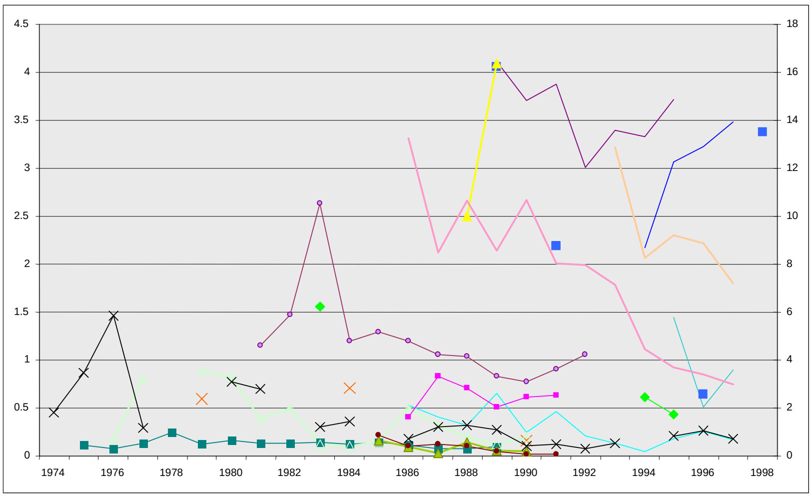


Table 3: A summary of the main characteristics from six elasmobranch fisheries

Fishery	Species	Catch Level t/y	Management System	Stock Assessment Methods	Status	References
Southern Australian shark fishery	*Galeorhinus galeus*, *Mustelus antarcticus* and other spp	2,800	Controls on amounts of gear (licenses)	Surplus production, delay-difference and age-structured models	Overexploited, under recovering regulations	Walker 1999 (FAO FTP 378)
Canadian porbeagle shark fishery	*Lamna nasus*	850	TAC (250 t), fishing licenses and fishing restrictions	Catch curves, catch rate trends and age structured model	Overexploited, under severe recovering regulations	Campana et al. 1999 and 2001
New Zealand shark fisheries	*Galeorhinus galeus, Squalus acanthias, Callorhinchus milii, Mustelus lenticulatus, Raja* spp, *Hydrolagus* spp and 15 other spp	17,000	ITQs (Individual Transferable Quotas) and TACs	None, quotas established using ad hoc methods (proportion of past catches	Recovered after exploitation or unknown	Francis 1999
East Coast USA shark fishery	39 species, mostly *Carcharhinus*	3,500	TAC	Bayesian surplus production models	Overexploited, under recovering regulations	Branstetter 1999 and MacAllister et al. 1998
Mexican shark fisheries	35 species, mostly *Carcharhinus*	35,000	5 prohibited spp and other simple regulations	None	Unknown, likely to be heavily exploited	Castillo et al. 1998 and Bonfil 1997
Argentinean shark fisheries	*Mustelus schmitii, Galeorhinus galeus, Carcharhinus brachyurus* and 10 other spp	35,000	None	None	Unknown, likely to be heavily exploited	Chiaramonte 1998

LECTURE 5 - SIMPLE METHODS AS AIDS IN STOCK ASSESSMENT: ESTIMATION OF MORTALITY AND DEMOGRAPHIC EVALUATION TECHNIQUES (LIFE TABLES)

Estimation of mortality

Here, we briefly review some concepts and methods that can be used for the estimation of mortality. Mortality is one of the key parameters in fisheries stock assessment and is very difficult to measure directly. Often the best we can do is estimate it using indirect methods.

In fisheries, we often assume three types of mortality, total (Z), fishing (F) and natural (M) mortalities

$$Z = M + F$$

Mortality rates are generally expressed as *instantaneous* mortality rates or mortality rate *coefficients*. This means that the *net rate* of mortality is equal to

$$1 - e^{-Z} \text{ or } 1 - e^{-(M+F)}$$

and that the survival rate (or what is left after mortality occurs) is the opposite of this.

Thus total survival rate is equal to

$$e^{-Z}$$

In other words, an instantaneous total mortality rate of 0.8 is equal to a survival rate of

$$e^{-0.8} = 0.449 \qquad \text{or almost a 45\% survival rate}$$

and is equivalent to a net or finite rate of total mortality of 0.551.

Mortality can be calculated or estimated using the following methods:

Catch curve

For total mortality Z, the catch curve or length-converted catch curve is a common method but it requires good knowledge of the age of the fish. If we assume that:

a) fish are fully recruited to the fishery,

b) catch is proportional to the abundance of each age class (no selectivity in the gear),

c) recruitment is constant for the last few years,

d) we know the catch of fish at each age in a short (instantaneous) time,

then Z between two ages is easily calculated as:

$$Z = -\ln(N_{a+1}/N_a)$$

Usually **Z** is calculated as the slope of a plot of the natural logarithm of catch at age for fully recruited ages, by doing a linear regression as in the following equation:

$$\ln(C_a) = b - Za$$

where $\mathbf{C_a}$ is the catch at age a, **b** is the intercept, and **Z** is the instantaneous mortality rate (slope of the regression) and **a** the age.

Approximate methods

A couple of approximate methods were developed by BEVERTON & HOLT (1956) who showed that (we skip the mathematical derivation):

$$Z = 1/(t_{avg} - t')$$

Where $\mathbf{t_{avg}}$ is mean age of fish at age **t'** and older and **t'** is the age where fish are fully exploited. They also showed that:

$$Z = K\,((L_{inf} - L_{cavg})/(L_{cavg} - L_c))$$

where **K** and $\mathbf{L_{inf}}$ are parameters of the VBGM (von Bertalanffy growth model), $\mathbf{L_c}$ is the 50% retention length (length of recruitment to the fishery) and $\mathbf{L_{cavg}}$ is the average length of the entire catch.

HOENIG (1983) gave the following equation for calculating **Z** from longevity ($\mathbf{t_{max}}$)

$$Z = e^{(1.46 - 1.01(\ln tmax))}$$

where $\mathbf{t_{max}}$ is the longevity in years (i.e. maximum age of the species).

Finally, PAULY (1980) gives another equation as follows:

$$\ln M = -0.0152 - 0.279 \ln L_{inf} + 0.6543 \ln K + 0.463 \ln T$$

Where **T** is temperature of the sea the species lives in and **K** and $\mathbf{L_{inf}}$ are from the VBGM as above.

These methods only give very rough, sometimes highly imprecise estimates of mortality, and they should be used with caution.

Changes in ratio method

The changes-in-ratios estimation method can be used to estimate instantaneous fishing mortality (**F**) rates for fish of separate sexes. The method assumes that the observed sex ratios before ($\mathbf{r_1}$) and after removal ($\mathbf{r_2}$) are representative of the population.

The method says that:

$$F_x = r_1 \ln (r_2)/[1+ 0.5 \ln (r_2) - r_1]$$

and

$$F_y = F_x + \ln (r_2)$$

where

$r_1 = R_x y_1/R_y x_1$ and $r_2 = x_2 y_1/x_1 y_2$

x and **y** are numbers of each sex in the population (or survey), 1 and 2 are time indices and **Rx** and **Ry** the removals (catches) of each sex between time 1 and 2.

Demographic evaluation techniques - Life tables

As outlined above, a life table provides a snapshot of the demographic parameters of a population. For this, a table is constructed that represents a summary of the survivorship and the reproductive output for each age of the population. The parameters we need to know are the maximum age, the survivorship for each age ($\mathbf{l_x}$, where ***X*** denotes age), and the age-specific natality ($\mathbf{m_x}$). For simplicity, life tables are usually only constructed for the female part of the population.

Given estimates of natural mortality **M** for each age or for an age group **t** (e.g. mortality of juveniles and mortality of adults) we can calculate survivorship as:

$$l_x = N_o(e^{-Mt})$$

where **No** is initial number of individuals and **e** is as above

The following equations give the formulas for the calculation of the demographic parameters net reproductive rate ($\mathbf{R_0}$), generation time (**G**), population doubling time ($\mathbf{t_{x2}}$), and most importantly for us, the observed rate of increase (**r**):

$$R_0 = \sum l_x m_x$$

$$G = [\sum l_x m_x x] / R_o$$

$$t_{x2} = \ln 2/r$$

$$\sum l_x m_x e^{-rx} = 1$$

Note that in order to calculate **r**, it is necessary to solve the last equation, known as the Euler-Lotka equation. This can be done using an iterative method such as the ‘solver’ in a computer spreadsheet (Excel).

Table 4 shows an example of how to construct a life table and calculate the above parameters. This example is based on the bonnethead shark *Sphyrna tiburo* from the Gulf of

Mexico. Life history information was taken from the literature (PARSONS 1993). Mortality for juveniles was taken as similar to that found for the lemon shark *Negaprion brevirostris* by MANIRE & GRUBER (1993), and adult mortality was estimated using HOENIG's (1983) equation (see preceding section).

Table 4: Life table for the bonnethead shark taken in the fishery of the Gulf of Mexico

Age	Survivorship l_x	Natality m_x	$l_x * m_x$	$l_x * m_x * x$
0	0.475	0	0	0
1	0.335	0	0	0
2	0.236	0	0	0
3	0.166	4.65	0.774	2.321855
4	0.117	4.65	0.546	2.182544
5	0.083	4.65	0.385	1.923367
6	0.058	4.65	0.271	1.627168
7	0.041	4.65	0.191	1.338346
8	0.029	4.65	0.135	1.078325
9	0.020	4.65	0.095	0.855246
10	0.014	4.65	0.067	0.669943
11	0.010	4.65	0.047	0.519541
12	0.007	4.65	0.033	0.399574
	1.593	46.5	2.544	12.916

The last row is the sum of the 13 age groups.

The sum of the fourth column in Table 4 is the net reproductive rate (**R_0**) i.e. the total reproductive output of one female over her lifetime. In this example, the values of each parameter are **R_0** = 2.544, **G** = 5.007, **t_{x2}** = 2.3019 and **r** = 0.2. To find **r**, an extra column must be included in the spreadsheet, with each cell representing the corresponding term **$l_x m_x e^{-rx}$**. Then, the sum of this column is forced to take the value of 1 (one) and 'solver' is used to find the value of **r** that satisfies the condition.

A modification of this demographic technique incorporates some degree of 'density-dependent' response to exploitation of the population (due to increases in juvenile survival) can be used to calculate the 'rebound potential' of the species (SMITH et al. 1998).

LECTURE 6 - SURPLUS PRODUCTION MODELS: POPULATION GROWTH AND BIOMASS DYNAMIC MODELS - SCHAEFER MODEL, FOX MODEL, AND PELLA-TOMLINSON MODEL

Population growth and biomass dynamic models

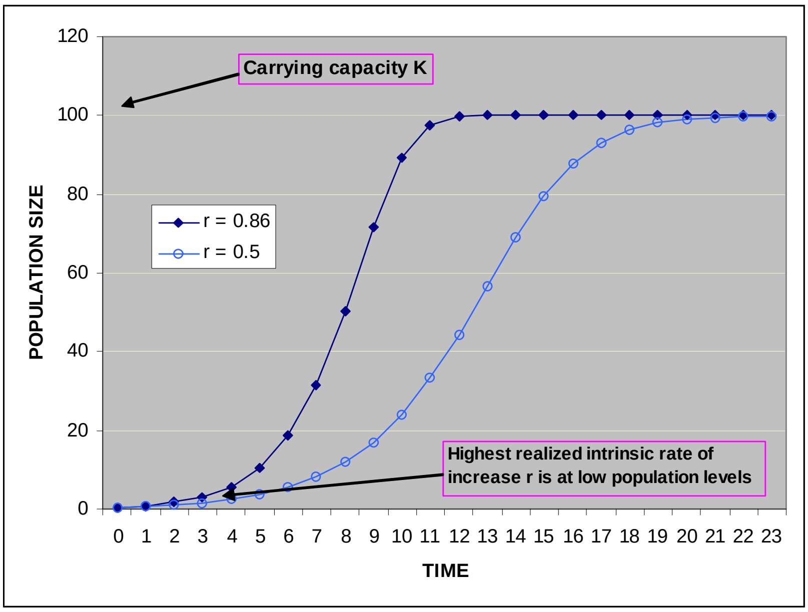
Population growth has been modelled in several ways. The most commonly used logistic model of population growth has been found to fit a large number of populations both in nature and in captivity. This model is expressed in the following way:

$$\frac{dB}{dt} = rB(1 - \frac{B}{K})$$

where **B** is biomass, **K** carrying capacity, and **r** intrinsic rate of population increase.

The carrying capacity of the system: **K** (or $\mathbf{B}_\infty$) is the maximum population size that can be achieved. Mortality, age-structure, reproduction and tissue growth are all included in a simple parameter called the *intrinsic rate of increase*, or *intrinsic rate of production*: **r**. In theory, the *intrinsic rate of increase* is fully realised at the lowest population level and *the finite rate* of population growth is highest at the midpoint of **K** (or half the carrying capacity**)**. This is shown in Figure 13. The population growth is shown for two different values of **r**.

Figure 13: Plot of population growth



The SCHAEFER (1954) model (also known as Biomass Dynamics Model) is the most commonly used surplus production model. It is based precisely on the logistic population growth model. The continuous logistic model can also be written as a discrete model as follows:

$$B_{t+1} = B_t + rB_t(1 - \frac{B_t}{K})$$

Schaefer model

When catch is included in the above equation, we obtain the Schaefer surplus production model:

$$B_{t+1} = B_t + rB_t(1 - \frac{B_t}{K}) - C_t$$

Where

$$C_t = qfB_t$$

C is catch, **q** is the catchability coefficient, **t** is time **t** and **f** is effort. In the Schaefer model above, the middle term is known as surplus production. If surplus production is greater than catch, population size increases; if catch equals surplus production, catch is sustainable and population size remains constant ($\mathbf{B_{t+1}} = \mathbf{B_t}$), if catch is greater than surplus production the population size declines.

The Schaefer model has the following assumptions:

a) there are no species interactions,

b) **r** is independent of age composition,

c) no environmental factors affect the population,

d) **r** responds instantaneously to changes in **B** (no time delays),

e) **q** is constant,

f) there is a single stock unit,

g) fishing and natural mortality take place simultaneously,

h) no changes in gear or vessel efficiency have taken place,

i) catch and effort statistics are accurate.

In practice, many of the above assumptions are not met but this does not mean that the method cannot be used. As long as it is used critically, the Schaefer model is a good tool for an initial stock assessment.

There are at least two data requirements for this model: a time series of total catch data (including discards, bycatches, etc.) and a time series of abundance data (usually CPUE but it is much better if surveys are available which are independent of the fishery). The abundance data can be constructed if we have effort data corresponding to a time series of catches and if we assume that CPUE is related to abundance linearly. The management parameters of importance from the Schaefer model are given by:

$$MSY = r\,K/4$$

$$B_{MSY} = K/2$$

$$\text{Optimum effort } (f_{MSY}) = r/2q$$

Fox and Pella-Tomlinson models

Other surplus production models have been proposed which represent fisheries more 'realistically'. First is the Fox model (FOX, 1970), based on the Gompertz population growth model. The Fox model equation is:

$$B_{t+1} = B_t + rB_t(1 - \frac{\ln B_t}{\ln K}) - C_t$$

The model is supposed to be more "realistic" because it assumes that the population can never be driven to total extinction. This sounds intuitive but is probably wrong in the light of severe depletion of fishery resources in recent years and well-documented extinctions of terrestrial species caused by humans.

The management parameters of the Fox model are given by:

$\mathrm{MSY} = \mathrm{rKe}^{-1}/\mathrm{lnK}$

$\mathrm{B}_{\mathrm{MSY}} = \mathrm{Ke}^{-1}$

$\mathrm{f}_{\mathrm{MSY}} = \mathrm{r/q\ lnK}$

PELLA & TOMLINSON (1969) proposed a generalised model that can take any shape including that of the Schaefer (m = 2) and Fox (m = 1) models (here m is a new shape parameter not related to m parameters defined above).

$$\frac{dB}{dt} = rB - \frac{rB^m}{K}$$

However, there is a price to be paid for this 'improvement' and that is the need to estimate another parameter to fit the model to data. Despite the 'flexibility' of this model, the fit will probably be worse than with either the Schaefer or the Fox models. The more parameters estimated, the lower the performance of the model.

LECTURE 7 - MODELS AND DATA: FITTING MODELS TO DATA AND PARAMETER ESTIMATION; THE IMPORTANCE OF DATA CONTRAST; DANGERS OF THE ASSUMPTION OF LINEARITY BETWEEN CPUE AND ABUNDANCE; EARLY CONCEPTIONS ABOUT SHARK STOCK ASSESSMENT MODELS

Fitting models to data

Some of the models used in fisheries stock assessment are very simple but the estimation of parameters to fit the models to the data is not always easy. In the case of the surplus production models above, there are three main approaches commonly used to estimate parameters.

1 Equilibrium

We could assume equilibrium conditions, i.e. so far all the catches observed in the fishery are sustainable. This is **WRONG and must always be avoided**. Equilibrium methods were used decades ago to simplify the calculation of parameter values. However, modern computers now allow the use of more sophisticated methods mentioned below. There is no longer any excuse to assume equilibrium. Never use equilibrium methods.

2 Linear regression

A second option is to use linear regression e.g. the Schaefer model, which can be expressed as a linear equation. Standard regression methods can be used to find the values of the parameters to fit the model to our data.

Given the Schaefer model equation for biomass dynamics in a fishery:

$$B_{t+1} = B_t + rB_t(1 - \frac{B_t}{K}) - qf_tB_t$$

we have that

$$U_t = \frac{C_t}{f_t} = qB_t \qquad \text{and} \qquad B_t = \frac{U_t}{q}$$

(where $\mathbf{U_t}$ is CPUE in year **t).**

Thus, substituting the second equation into the first we arrive at:

$$\frac{U_{t+1}}{q} = \frac{U_t}{q} + r\frac{U_t}{q}(1 - \frac{U_t}{qK}) - f_tU_t$$

Rearranging, dividing by U_t and multiplying by **q** we obtain:

$$\frac{U_{t+1}}{U_t} - 1 = r - \frac{r}{Kq} U_t - q f_t$$

The above equation is in reality a linear equation of the general form:

$$Y = b_0 + b_1 X_1 + b_2 X_2$$

This can be solved easily using the multiple regression facilities available in most computer spreadsheet programs.

Although regression methods can be applied easily to solve fisheries models, it has been demonstrated that they can give very biased answers (UHLER 1979). They can also produce obviously wrong answers, such as negative values of **r** or **q**, which are biologically impossible. The general moral is that illogical answers only mean bad data!

3 Time-series fitting

The most recommended method to fit fisheries models to data is time-series fitting. According to HILBORN & WALTERS (1992), Pella & Tomlinson (1969) first proposed this method. It involves taking an initial estimate of the stock size at the beginning of the time series of data (catch and CPUE) and using the Schaefer model to predict each point in the entire time series of data. Initial parameter values (guesses) are iteratively adjusted to minimise the difference (ε_t) between the observed CPUE (Ut) and the CPUE (Ût) predicted by the Schaefer model:

$$\varepsilon_t = (\hat{U}_t - U_t)^2$$

Where **Ût** (CPUE) is:

$$\hat{U}_t = q \hat{B}_t$$

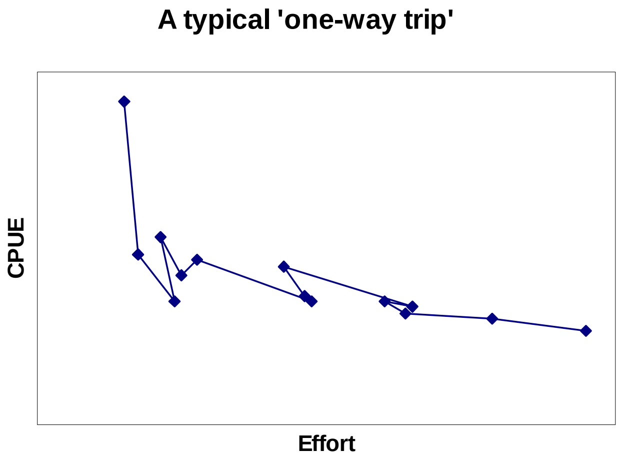
This means that we have to estimate **r**, **q**, **K**, and the initial biomass size $\mathbf{B_0}$. Usually, using non-linear estimation procedures (such as those available in spreadsheets) solves the problem of finding the best parameter values (while minimising the above difference between observed and predicted values for CPUE).

Data quality

An important principle, often overlooked in fisheries science is that **we cannot understand how a fish stock will respond to exploitation until the stock has been exploited.** A good stock assessment depends as much on having an adequate model to describe the system dynamics as on the quality of the data the model is fitted to. Data quality does not only mean whether there are biases or errors, but also on how much useful information is embedded in the data. The data needs to include historical **variation** in stock size and fishing pressure to estimate the parameters of the model with any degree of reliability. Otherwise, an assessment can produce a meaningless set of numbers that are not a good representation of the stock dynamics.

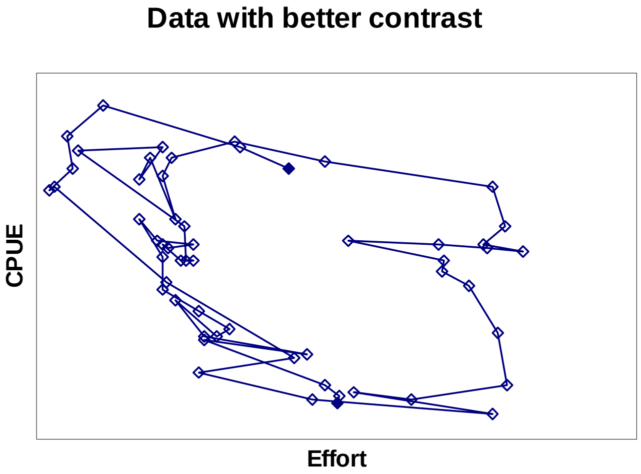
The most important quality of fisheries data is the degree of **contrast** embedded **in the data**. Data must have high contrast i.e. ideally having data points at low stock sizes with low fishing effort (for information about **r**), at high stock sizes with low fishing effort (to estimate **qK**) and at high fishing effort (high or low stock sizes) to estimate **q**. This is very difficult to find because of the way most real fisheries develop. Typically, low effort at large stock sizes is gradually increased to very high levels resulting in low stock sizes. Thus we usually miss having a point of low fishing effort at low stock sizes. This leads to the most **uninformative** type of **data,** typically known as the "one way trip", in which the data shows an increase in effort with time and a declining CPUE (see Figure 14). This **lack of contrast** in the data makes for very **uncertain parameter estimates**. The standard deviation of such parameters is often as large as or larger than the parameter estimates, clearly indicating very unreliable results. Under such circumstances, management will be severely handicapped.

Figure 14: Relationship between effort and CPUE with poor data contrast (modified with permission from HILBORN & WALTERS, 1992)



Data with **better contrast** can be obtained when a fishery shows a period of increased effort followed by a period when effort was reduced gradually so that the stock was allowed to rebuild after heavy exploitation. Hilborn & Walters (1992) describe this as 'moving up and down the isocline'. Note from Figure 15 how there is a better scatter in the data points instead of them all falling on one single line as before. These data have more inherent variation and contrast than the example in Figure 14 (the dark squares in the figure represent the start and finish points of the time series). Typically, the model parameters are much more precisely estimated than in a 'one-way trip' case, but the slow change in effort does not usually provide enough contrast to the data. In cases like the one in Figure14, the standard deviation of the parameters is usually about half or less than half the parameter estimates and although not good enough, it is better than in one-way trip data.

Figure 15: Relationship between effort and CPUE with better data contrast (modified with permission from Hilborn & Walters, 1992)



Data sets with **high contrast** have relatively rapid changes back and forth between high and low effort. In these cases, parameter estimates can be much more precise. Other factors such as the total number of points in the time-series data and the intrinsic variability of the data also have an influence on the final precision of parameter estimates for the model.

In summary, when fitting models to fisheries data it is imperative to look at the uncertainty in the parameter estimates, not only to a single 'goodness of fit' measure such as the sum of squares. It is always advisable to apply different models to the same data set and compare the results, trying to validate results or to ask questions about why they might be different and what the implications of this are. In addition, it is important to learn how to use uncertain ('bad') results to try to improve the contrast in the data through careful thought and planning of management regulations aimed at improving data quality (such as large variations in effort over short periods of time).

The relationship between CPUE and abundance

At the core of most fisheries models using CPUE information, there is an important assumption: that the abundance of the fish stock (or other aquatic animal) has a direct relationship with CPUE. In other words, these models assume that CPUE is an index of abundance. For fisheries where the fishing season is a single pulse or over a relatively short part of the year, this can be expressed mathematically as:

$$C_t = qf_tB_t \longrightarrow U_t = qB_t$$

where $\mathbf{U_t}$ is CPUE in year **t**.

According to the last equation, CPUE is directly linked to biomass (abundance) by a constant factor **q**, the catchability factor. The above model assumes that there is **proportionality** (i.e. a linear relationship) between CPUE and the abundance of the stock. This is a very dangerous but necessary assumption in most fisheries models; it should be questioned and checked for. Two other (non linear) relationships between CPUE and abundance are as follows:

a) **Hyperdepletion** occurs when the stock abundance falls at a much slower rate than the CPUE. The CPUE tells us the stock abundance is low when it is still high. If it is not detected the stock appears to be overexploited even though it is in a good state. This can occur when the species is only being exploited in a relatively small part of its range (e.g. when there are natural refuge areas such as deeper waters or rough grounds where the gear cannot fish). As a result, the exploited part of the stock decreases rapidly but the overall abundance of the stock does not. Given that the abundance index (CPUE) is based only on data from the fishing grounds, it will decrease faster than if it was based on fishing over the entire geographical range of the stock.

b) **Hyperstability** happens when the stock abundance falls faster than the CPUE, giving the impression that the stock abundance is still high when it is already dangerously overexploited. Hyperstability is a well-known phenomenon in fisheries for highly gregarious or schooling species such as herrings, sardines, anchovies and tuna. In these fisheries, searching for fish schools is highly efficient and as a result, fishing an entire school is relatively quick and efficient. Hyperstability is far more common and results in the collapse of fishing stocks.

A lack of proportionality between CPUE and effort can be detected using mapping and stratification of CPUE and effort data to analyse spatial patterns, or by using depletion experiments to gain additional information. However, a more straightforward if not easier method is to obtain **fishery-independent indices of stock abundance**. Research cruises or coordinating efforts with fishermen can be used to perform orchestrated experiments to fish using alternative areas or methods, e.g. following a systematic sampling design.

Early conceptions about shark stock assessment models

Perhaps the most influential works on shark stock assessment but not necessarily the best were those of Holden in the 1960s and 1970s. HOLDEN (1977) pointed out that sharks were different from bony fishes in terms of their biology but unfortunately arrived at the wrong conclusion - that classic fisheries models e.g. surplus production models could not be applied to sharks and rays. Holden dismissed these models and called for new models to be developed. He stated that the following assumptions of surplus production models do not hold for sharks:

a) immediate response in the rate of population growth to changes in population abundance,

b) independence of the rate of natural increase from the age composition of the stock.

These conclusions were based predominantly on the time delays caused by the longer reproductive cycles and reproductive methods of sharks, which in Holden's view would cause a direct linear stock-recruitment relationship. Generally, because of this very influential paper, surplus-production models have been ignored for shark stock assessment and new methods and models have been searched for e.g. the more detailed age-structured models of WOOD et al. (1979) and WALKER (1992).

The problem is not that existing fishery models were inadequate but how they were being applied. The chief obstacle for the use of classic surplus-production models in the 60's and 70's was the equilibrium constraint mentioned above.

The dangerous consequences of this assumption - that populations were in equilibrium at all exploitation levels - are well known and explicitly warned against in fishery textbooks (PITCHER & HART 1982, HILBORN & WALTERS 1992). The availability of non-linear optimisation methods on computer allows surplus production models to be applied more easily. PUNT (1991), PRAGER et al. (1994), POLACHEK et al. (1993) and BABCOCK & PIKITCH (2001) have applied the methods to organisms as slow growing as whales and sharks. The reappraisal of surplus production models has shown that most of the problems result from the quality of the fisheries data (HILBORN 1979). Simple surplus production models can perform better than the more elaborate and biologically detailed age-structured approaches (LUDWIG & WALTERS 1985, 1989; PUNT 1991).

The difficulty in applying these models to sharks comes from the inadequacies in data available from fisheries and our knowledge of shark biology. This is expressed very clearly in ANDERSON (1990), ANDERSON & TESHIMA (1990) and BONFIL (1996).

The most common problem in fisheries science, independent of the species, is the lack of sufficient good-quality data, and the lack of contrast in that data. Another big problem (often overlooked) is that the more 'realistic' age-structured models are difficult to apply because data is much more detailed and expensive to obtain. Furthermore, the life cycles in terms of the basic parameters of age, growth and reproduction, have been only available for a few for species for the last 15 years (see PRATT & CASEY (1990) for a review). There are also relevant areas of elasmobranch population dynamics that are still largely unknown. For example, directly derived stock-recruitment relationships have never been documented for any elasmobranch, although the reproductive strategies of the group suggest a very strong relationship (HOLDEN 1973, HOFF 1990). The size, structure and spatial dynamics of most elasmobranch stocks are almost totally unknown. Inadequate knowledge of migration routes, stock delimitation and movement rates amongst them, can seriously undermine otherwise "solid" assessments and management regimes.

HOFF (1990) favours the use of dynamic surplus-production models for shark stock assessment for a variety of reasons. PUNT (1988, 1991) also reports dynamic surplus production models as the most reliable for management of Cape hake resources and baleen whales, when using a simulated fully age-structured population. Similar positive results are reported with a Schaefer model for a swordfish age-structured population (PRAGER et al. 1994). The results of BONFIL (1996) suggest that surplus production models are good enough for shark biomass assessment but not for management parameter estimation. Although generally inferior to the Deriso-Schnute model, both surplus production models are capable of estimating biomass and obtaining good biomass fits for most of the scenarios analysed.

LECTURE 8 - PARTIALLY AGE STRUCTURED MODELS: DERISO-SCHNUTE DELAY-DIFFERENCE MODEL, YIELD-PER-RECRUIT MODELS

Partially age-structured models are an intermediate between the simplistic surplus production models analysed above and the more sophisticated and realistic age-structured models. They represent a step forward from surplus production models because they incorporate additional information about the growth and mortality of the species in question. They do not have the demanding data requirements of fully age-structured models. They also have a smaller number of estimated parameters in comparison with age-structured models. They can be applied to fisheries with limited amounts of data while offering a more realistic representation of population dynamics.

Deriso Delay-Difference Model

The first partially age-structured model considered here is the delay-difference model first proposed by DERISO (1980). It was further generalised by SCHNUTE (1985). This simplification is not used very often in reality because more complicated computer based models are readily available.

The model incorporates four main types of information about a particular species:

a) body growth,

b) recruitment,

c) survival,

d) a measure of age-structure.

The main formula links present available biomass (exploitable biomass or that recruited in a given year) to available biomass and population numbers from the previous year. The advantages of the model are several simplifications allowing the incorporation of important population dynamics into a simple equation. Its most important characteristic is probably that the model allows for time lags in the dynamics of the stock, which are typical of a species with a slow growth and late age of entry to the fishery. The ability to take time-delay into account gives the name 'delay-difference' model. Below is a detailed derivation of the delay-difference model taken from HILBORN & WALTERS (1992).

The model assumes that body growth of the exploitable stock can be represented by a linear function (the Brody equation):

$$w_a = \alpha + \rho w_{a+1}$$

where $\mathbf{w_a}$ is body weight at age **a** and α and ρ are constants. This equation states that after a certain age, the typical von Bertalanffy model of increase in weight represented by Figure16 can alternatively be represented by a linear equation of weight at age **a** against weight at age **a+1**. In order to find the parameters α and ρ of the Brody equation, we must perform a linear regression as shown in Figure 17. Figure 17 shows several possible linear regressions based on different starting points. Which regression is chosen, (therefore which parameters α and ρ we use in the model) depends on the age of entry to the fishery.

Figure 16: A typical von Bertalanffy growth curve

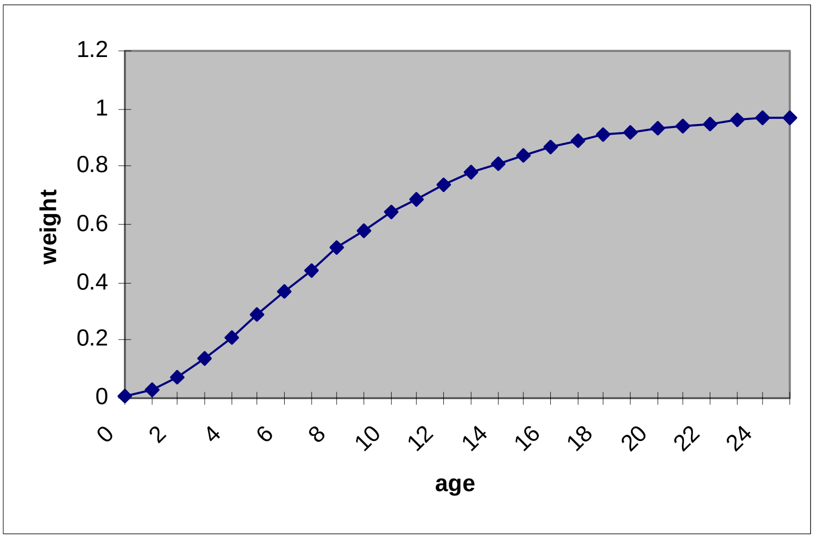
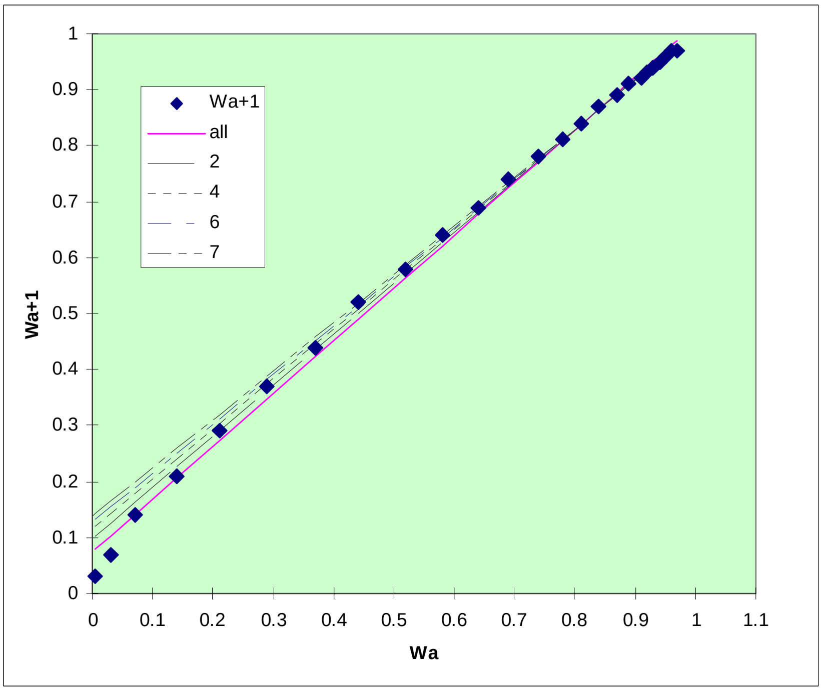


Figure 17: Regression to find α and ρ of the Brody equation



The delay-difference model also assumes that all fish older than age **k** (age of entry to the fishery) are vulnerable to fishing and have the same natural mortality **M**.

A second simplification of the model considers that the total survival rate (S_t)

$$S_t = e^{-Z}$$

can be decomposed into terms for constant and variable (harvest) survival:

$$S_t = \psi(1 - h_t)$$

where **ψ** is the natural survival rate and **h** is the harvest rate in year **t**. This assumes that harvest (fishing) takes place in a short time during the beginning or end of the year.

Biomass at age **a** can be represented as numbers at age (**N$_a$**) x average weight at age (**w$_a$**)

$$\mathrm{B}_a = \mathrm{N}_a \bar{w}_a$$

This can be extended for the whole exploited population plus the recruitment **R**

$$\mathrm{B}_t = \left[\sum_{a=k}^{a\max} \mathrm{N}_{t,a} \bar{w}_a \right] + w_k \mathrm{R}_t$$

where **k** is the age of recruitment (to the gear or fishery). Population numbers **N** can be written as survivors from last year at age **a-1** and all the weights at age can be written using the Brody equation, thus arriving to the following formula:

$$\mathrm{B}_t = S_{t-1} \left[\alpha \sum_{a=k+1}^{a\max} \mathrm{N}_{t-1,a-1} + \rho \sum_{a=k+1}^{a\max} \mathrm{N}_{t-1,a-1} \bar{w}_{a-1} \right] + w_k \mathrm{R}_t$$

Factoring out the terms that do not depend on age results in sums over age **k** and older for year **t-1**

$$\mathrm{B}_t = S_{t-1}\alpha \mathrm{N}_{t-1} + S_{t-1}\rho B_{t-1} + w_k \mathrm{R}_t$$

and total numbers in the population are:

$$\mathrm{N}_t = S_{t-1}\mathrm{N}_{t-1} + \mathrm{R}_t$$

But we can write the term αN_{t-1} of the equation as

$$\alpha \mathrm{N}_{t-1} = \alpha S_{t-2}\mathrm{N}_{t-2} + \alpha \mathrm{R}_{t-2}$$

and also, the term $\alpha S_{t-2} N_{t-2}$ can be expressed in terms of $\mathbf{B}_{t-1}$ and $\mathbf{N}_{t-2}$ using the equation for $\mathbf{B}_t$ above, as:

$$\alpha S_{t-2}\mathrm{N}_{t-2} = \mathrm{B}_{t\text{-}1} - \rho S_{t-2}\mathrm{B}_{t-2} - w_k \mathrm{R}_{t-1}$$

Combining the last two equations (substituting) and making some more algebraic manipulations we arrive at the delay-difference equation:

$$B_t = (1+\rho)S_{t-1}\mathrm{B}_{t\text{-}1} - \rho S_{t-1}S_{t-2}\mathrm{B}_{t-2} - \rho w_{k-1}S_{t\text{-}1}\mathrm{R}_{t-1} + w_k \mathrm{R}_t$$

This is the original form of the model and it requires 7 parameters to predict biomass dynamics and fit the model to catch and CPUE data:

a) ρ and w_k from the Brody growth equation,

b) ψ for the natural survival rate (no fishing),

c) a, b or a', b' for the stock recruitment relationship – please clarify - what are a, b or a'b',

d) B_0 for stock size at the beginning of the fishery,

e) q for catchability for the catch equation.

Recruitment can be modelled using either the Ricker or the Beverton and Holt equations, simplified by assuming that the population was in equilibrium (virgin population) when exploitation began.

For the Ricker recruitment model the equations are:

$$R_{t+1} = S_{t-k+1} e^{(a' - b' S_{t-k+1})} \qquad a' = \ln \frac{(R_0)}{b'} + B_0 b'$$

For the Beverton and Holt recruitment model the equations are:

$$R_{t+1} = \frac{a S_{t-k+1}}{b + S_{t-k+1}} \qquad a = R_0 \frac{(b + B_0)}{B_0}$$

Other parameters can be estimated externally or internally with some assumptions:

a) ρ and w_k are estimated directly from growth data,

b) ψ is estimated using external estimates of natural mortality M.

This leaves us with only 3 parameters to be estimated by non-linear methods:

a) b or b' for the stock-recruitment relationship,

b) B_0 - stock size at the beginning of the fishery,

c) q - catchability for the catch equation.

In other words, the delay difference model is simplified most by fixing values for the first 3 parameters listed above. It is fitted to the catch and effort data by finding the values of the last 3 parameters using non-linear iterative methods in spreadsheet software.

Yield per Recruit Model of Beverton and Holt

This model is also known as the Dynamic Pool Model. Although not strictly a partially age-structured model, it is reviewed here because it also has more biological detail than surplus production models but is not as powerful and detailed as the fully age-structured models reviewed below in Lecture 10.

The model describes the population in terms of the biological processes of growth, recruitment and mortality. It treats the exploited population as the sum of its individual members. The model incorporates more biological realism than surplus production models.

A shortcoming is that the model assumes there is no dependence between stock size and recruitment.

The yield-per-recruit model has the following assumptions:

a) there is a distinct spawning period and all fish recruit at the same time and age,

b) growth parameters do not change over time, stock size or age,

c) **M** is assumed known and constant over all ages, over time and stock size,

d) recruitment is constant and can be ignored.

This model is based on three equations, some of which we are already familiar with:

Von Bertalanffy Growth Model in weight (**W**):

$$W_t = W_\infty (1 - e^{-k(t-t_0)})^3$$

where k is the Von Bertalanffy growth coefficient

Exponential survival model:

$$N_t = R \cdot e^{-M(t_c - t_r)} \cdot e^{-(M+F)(t-t_c)}$$

where $\mathbf{t_c}$ is age at first capture and $\mathbf{t_r}$ is age of recruitment to the stock.

General yield equation:

$$Y = \int_{t_c}^{t_1} F \cdot N_t W_t dt$$

where **Y** represents yield (catch).

These three equations can be integrated (not shown here in the interest of space and simplification) to obtain the yield equation of Beverton and Holt:

$$Y = F \cdot R \cdot W_\infty \cdot e^{-M(t_c - t_r)} \cdot \sum_{n=0}^{n=3} \frac{\Omega_n}{F+M+nK} \cdot e^{-nK(t_c - t_0)} \cdot (1 - e^{-(M+F+nK)(t_1 - t_c)})$$

where:

a) **tc** is age at first capture,

b) **t_1** is maximum age of fish in stock,

c) **K** the von Bertalanffy growth coefficient,

d) $\Omega_0 = 1$, $\Omega_1 = -3$, $\Omega_2 = 3$, $\Omega_3 = 1$.

Because the level of recruitment is not known, the above equation is usually expressed in relative terms, as yield per recruit:

$$\frac{Y}{R} = F \cdot W_\infty \cdot e^{-M(t_c - t_r)} \cdot \sum_{n=0}^{n=3} \frac{\Omega_n}{F+M+nK} \cdot e^{-nK(t_c - t_0)} \cdot (1 - e^{-(M+F+nK)(t_1 - t_c)})$$

The model predicts the level of yield (catch) that is sustainable depending on the age of entry, maximum age in the stock and the level of natural and fishing mortality.

This model allows managers to investigate the effects of varying fishing mortality (**F**) or age of first entry (**t_c**) on yield. One disadvantage of this model is that the shape of yield curve is completely determined by growth and mortality. If the stock has a low rate of growth and high **M** the yield curve is asymptotical, (this wrongly suggests yield does not decrease as you fish harder and harder). Conversely, if the stock has rapid growth rate and low **M** the yield curve is dome-shaped.

The advantages of the yield per recruit model are that it:

a) is easy to use if you know **M**, **F**, the parameters of the growth equation, the ages of entry and maximum age,

b) does not require historical data of catch and effort,

c) provides more biological realism than surplus-production models,

d) is very useful for determining best age of entry (minimum size limits),

e) is very useful for examining effects of changes in effort on yield (fishing mortality).

However, its disadvantages are:

a) it unrealistically assumes constant growth and mortality rates,

b) it is more expensive to implement than surplus production models as age needs to be determined frequently in large samples,

c) the curve shape is predetermined and inflexible,

d) the model predicts yield even at infinite effort and this is unrealistic,

e) yield is not expressed in absolute terms so the real magnitude of the catch cannot be known.

LECTURE 9 - MODELS AND DATA II: INTRODUCTION TO BAYESIAN ESTIMATION

Bayesian estimation is the best and most powerful method for fitting fisheries models to data. It allows the incorporation of previous knowledge about the fishery into the estimation process, effectively helping to find more sensible solutions. The types of information that can be incorporated in Bayesian estimation are extremely flexible. It includes

a) fishery CPUE,

b) independent survey CPUE,

c) catches,

d) estimates of intrinsic rate of population growth from life-table analyses,

e) biological limits,

f) knowledge from similar stocks,

g) mark-recapture information,

h) other information.

Another advantage is that Bayesian estimation can tell us a lot about the uncertainty of the parameter estimates. The estimation is based mainly on using previous knowledge to assume a probability distribution for the estimated parameters. This distribution is known as the **prior probability distribution** or just ‘the prior’. Although relatively new, in recent years, Bayesian estimation has become the most powerful and accepted method to fit models to data in fisheries stock assessments.

Bayes theorem is based on **conditional probability**. It states that the probability (**Pr**) of a parameter or group of parameters given certain data is equal to the product of:

a) the probability of the data given the parameters, and

b) the probability of the parameters themselves,

divided by the sum of all possible parameter values of the product of

c) the probability of the data given the parameters, and

d) the probability of the parameters:

As shown in:

$$\Pr\{parameters \mid data\} = \frac{\Pr\{data \mid parameters\} * \Pr\{parameters\}}{\sum_{parameters} \Pr\{data \mid parameters\} * \Pr\{parameters\}}$$

The terms on the upper and lower right of the equation imply that we have previous knowledge about the shape of the distribution of the parameters. This is the strength of the method as it allows us to include additional ‘external’ information in the estimation process, such as biological or fisheries information.

Depending on the type of ‘external’ information that we want to incorporate, there are different possible distributions we can use for the parameters such as the binomial, normal, uniform, Poisson, multinomial and others. For more details about the types of distributions for different types of data, users should consult a statistical textbook.

A rudimentary but simple way to implement Bayesian statistics is to calculate the “Kernel” which is based on the sum of squares:

$$L(parameters) = SS^{-\frac{t-1}{2}}$$

Where **L** is the likelihood of the parameters, **SS** is the sum of squared differences between the real data and the estimated data points derived from a given set of model parameter values and **t-1** is the degrees of freedom (number of data points minus one).

$$\Pr(parameters \mid data) = \frac{SS^{-\frac{t-1}{2}}}{\sum\limits_{parameters} SS^{-\frac{t-1}{2}}}$$

LECTURE 10 - AGE-STRUCTURED MODELS: VIRTUAL POPULATION ANALYSIS, CATCH-AT-AGE MODELS

The most sophisticated class of stock assessment models are fully age-structured models such as Virtual Population Analysis (VPA) and Catch-at-age analysis (CAGEAN) which are two of the most commonly used in this category. These methods are recursive recipes (algorithms) which track the history of each cohort in the exploited population back in time from the present to the time each cohort was born or more commonly to the time it recruited to the fishery. The aim of the model is to reconstruct the entire exploited population to estimate fishing mortality and numbers at age for each age class in each year (see also introduction to VPA and CAGEAN in Lecture 4 above).

Virtual Population Analysis

The basis of this method is to assume that - if we know that this year we have zero fish of the oldest age left alive, and we know how many we caught last year (in theory the last fish of that age), and if we also know the instantaneous natural mortality rate - then, for fisheries where fishing period is short (and it can be assumed that there is no natural mortality during that short period of time):

$$N_t = N_{t+1} + C_t + D_t$$

$$N_t - D_t = N_{t+1} + C_t$$

$$D_t = N_t (1-s)$$

$$N_t - N_t (1-s) = N_{t+1} + C_t$$

$$N_t - N_t + N_t s = N_{t+1} + C_t$$

$$N_t s = N_{t+1} + C_t$$

$$N_t = (N_{t+1} + C_t) / s$$

Where **N** is number of fish, **C** is catch, **D** is deaths (numbers dying), **t** is time (year) and **s** is the finite survival rate.

The last equation above is the key equation for VPA or cohort analysis when fishing takes place in a single short period of time during which we can consider **M** to be negligible. It allows us to calculate the numbers last year from the numbers this year, the catch and natural mortality. Because we assume there were no more fish left of the oldest age this year (we fished them all or they died), we can calculate the numbers last year using only catch and mortality.

An example is from the herring stock of the Georgia Strait in British Columbia, Canada. Herring only live to a maximum 9 years. They are recruited to the fishery at age 2. The fishery takes place on only a couple of days each year when the fish spawn in large aggregations. The information we need for the cohort analysis is an estimate of M, which for this stock are 0.6, and the total catch of fish in each age class for each year. A table with such data would represent the total numbers in the catch for each age class for 9 years. Using such data and the following equations we can obtain estimates of:

a) The population at the end of the fishery each year,

b) The population just before the fishery each year,

c) The harvest rate,

d) and the instantaneous fishing mortality.

For this we will need the equation for numbers at the start of the year

$$N_t = (N_{t+1} + C_t) / s \qquad (1)$$

and the following equations:

a) For numbers alive at the beginning of the fishery

$$N_t' = Nt\ s \qquad (2)$$

b) For the harvest rate

$$h_t = C_t/N_t' \qquad (3)$$

c) for fishing mortality

$$F_t = - \ln (1-h_t) \qquad (4)$$

Table 5 shows the results of the calculations for only one cohort; the other cohorts are treated in the same way in a full VPA. For the last cohort in the last year of data we assume there are no fish left, they all die after age 9 in 1979. The table is constructed for this cohort using equation (**1**) to calculate cohort size at the beginning of each year (note that fish age 9 in 1979 were age 8 in 1978, etc.):

Table 5: Herring stock of the Georgia Strait in British Columbia, Canada (taken from HILBORN & WALTERS 1992 with permission)

Year	Age	Catch	Cohort size at start of year	Cohort size before fishery	Harvest rate	Instantaneous fishing mortality
1979	9	0	0	-	-	-
1978	8	1050	1750	1050	1.00	INFINITE
1977	7	2640	7317	4390	0.60	0.92
1976	6	6182	22498	13499	0.46	0.61
1975	5	14145	61071	36643	0.39	0.49
1974	4	8333	115674	69404	0.12	0.13
1973	3	7813	205811	123487	0.06	0.07
1972	2	1286	345162	207097	0.01	0.01

This analysis is done for one cohort only. For a complete VPA, the same method should be applied for all cohorts that are no longer present in the fishery. One remaining problem is that we do not have information to do the analysis for incomplete cohorts (those still present in the fishery) and these are the most important ones.

One way to solve the problem of incomplete cohorts is to estimate the fishing mortality rate of cohorts currently being fished and use this to estimate the sizes of the incomplete cohorts. Two ways to do this are to obtain population size estimates from surveys, mark-recapture methods, or (most commonly) to assume a value for the current **F** and estimate previous values from there.

This last case is known as the terminal **F** assumption; it comes from the following equation:

$$N_t = \frac{C_t}{(1-e^{-z_t})}\left(\frac{F_t+M}{F_t}\right)$$

There are two ways to estimate **F**, one is from tag-recapture methods, and the other is from effort data assuming that **q** is known using:

$$F = fq$$

The catchability coefficients **q** for each age can be obtained from the complete cohorts, assuming **q** is constant over time we can use it with effort data to calculate **F** for each age. Another variation of this approach is known as the 'tuned' VPA, which uses the **q'**s from complete cohorts and uses these to derive a new set of **q'**s for the incomplete cohorts.

The problems of VPA are that using the wrong estimate of **M** can lead to severely overestimated or underestimated cohort sizes. More worryingly, when catchability increases as the stock declines in size, VPA has been found to have large errors, overestimating the stock size and probably recommending larger catches than can be sustained. This can lead to overfishing of the stock. A second problem is that to obtain the necessary catch-at-age data it is essential to perform routine age analysis of samples of the catch. If the ages are wrongly estimated this will introduce systematic biases to the results of the analysis.

Catch-at-age analysis

CAGEAN or statistical catch-at-age methods are very similar to VPA. The difference is that formal statistical methods are used to estimate the current abundance of incomplete cohorts. They also provide a method to estimate natural mortality rate provided that the data have clearly contrasting levels of fishing effort and total mortality rate.

CAGEAN starts by using the catch curve concept described earlier (Lecture 5), to calculate the instantaneous total mortality rate for each cohort from the catch at age data. In the same way we can build catch curves for the catches at age of one single year. The same concept can be applied to the catches of all cohorts between subsequent years. The equation used for normal catch curves (one single year of data) is a linear regression of the numbers-at-age against age. The slope of the line is the estimate of **Z** and the intercept of the Y-axis represents the logarithm of the recruitment (**R**) times the vulnerability of the fish to the gear (v):

$$\ln(C_a) = \ln(Rv) - Za$$

A modified version of the catch curve is used to estimate mortality within a single cohort as follows:

$$\ln(C_{aj}) = \ln(R_j v) - Za$$

where **j** denotes a specific cohort. This allows the estimation of the total mortality and the relative recruitment ‘strength’ of each cohort. This method assumes that fishing and natural mortality are constant and that vulnerability to the fishing gear is constant above a given age. However, these catch curves do not allow us to estimate natural mortality rate or vulnerability, so their usefulness is limited. CAGEAN can be modified as shown below.

Paloheimo method

The Paloheimo method (PALOHEIMO 1980) is the simplest version of CAGEAN; it is analysed here in some detail. This method uses the following equations and some algebra to arrive at another important equation:

$$C = N \frac{F}{F+M}\left[1 - e^{-(F+M)}\right]$$

This equation assumes that fishing mortality acts separately from natural mortality and takes a fraction (**F/Z**) of the total mortality.

$$N_a = \mathrm{Re}^{-\Sigma F - \Sigma M}$$

The above equation relates numbers at age **a** to recruitment times, accumulative fishing and natural mortality for each previous age.

We also use the following equation:

$$F = fq$$

Where **f** is effort and **q** is catchability. The above equations combined and manipulated using algebra give us:

$$\frac{C_a}{f} = \mathrm{R}e^{-q\Sigma f - \Sigma M}\, q \cdot \frac{1-e^{-z}}{Z}$$

This equation relates CPUE at age to recruit numbers and catchability, total and natural mortality and effort.

Applying more algebra this becomes:

$$\ln\left(\frac{C_a}{f}\right) = \ln(\mathrm{R}q) - q\sum f - \sum M + \ln\left(\frac{1-e^{-z}}{Z}\right)$$

Then, if we assume that **M** is constant over years and use a well-known approximation for the last term (which is valid for values of **Z** that are not too large)

$$\ln\left(\frac{1-e^{-z}}{Z}\right) \approx -\frac{Z}{2}$$

then using algebra we obtain the final Paloheimo equation:

$$\ln\left(\frac{C_{aj}}{f}\right) = \ln(\mathrm{R}_{\text{j-a}}q) - q\left(\sum_{k=j-a}^{j-i} f_k + \frac{f_j}{2}\right) - M(a - \tfrac{1}{2})$$

where **j** = calendar years, **a** = age, and **k** = the years when cohort has been fished.

The above equation is a linear multiple regression of the form:

$$Y = b_0 + b_1X_1 + b_2X_2$$

where Y is yield.

Given the data, this equation can be easily solved with standard multiple regression packages to obtain estimates of **Rq**, **q**, and **M**.

If we were to apply the above method to the data in Table 6:

Table 6: Catch and effort data for the 1971 cohort of Lake Eire Perch (taken from HILBORN & WALTERS 1992 with permission)

Age	Catch	Effort
2	103	15.9
3	59	15.4
4	11	13.5

The estimates of the parameters would be as follows:

ln (Rq) = 2.37

q = - 0.22

M = 4.34

Table 7: Parameter estimates for Lake Eire Perch using the Paloheimo method (taken from HILBORN & WALTERS 1992 with permission)

Parameter correlations			
	Rq	**q**	**M**
Rq	1		
q	-0.71	1	
M	-0.69	-0.999	1

These results of parameter estimates shown in Table 7 are not as good as hoped. As a result of poor data contrast, **q** is negative (which is impossible), while **M** is extremely high. To be able to perform this catch-at-age analysis we needed the fishing effort as well as the catch-at-age for each year for this cohort. The fishing efforts are all of the same magnitude and almost constant (very poor contrast), this is why there is a strong negative correlation between **q** and **M**.

If instead we were to analyse data for three cohorts of Lake Eire perch simultaneously using this method, we would have to resort to using dummy variables or what is known as an experimental design table, to perform the multiple linear regression. In this case, the equation becomes:

$$Y = b_1X_1 + b_2X_2 + b_3X_3 + b_4X_4 + b_5X_5$$

where the first three **b**'s represent the recruitment level of each cohort. The dummy variables $\mathbf{X}_{\mathbf{1\text{-}3}}$ take the values 1 or 0 depending on which cohort we are analysing, so that the corresponding **b** (recruitment) is taken into account or not. The last two terms (b_4X_4 and b_5X_5) are the same as before, they are the efforts and the number of years of accumulated natural mortality. If we were to perform the analysis, the results would still not be satisfactory. There is still poor data contrast in the effort for this set of data (see HILBORN & WALTERS 1992) despite the fact that there is data for 3 different cohorts and 4 different years. We still cannot differentiate between the effects of natural and fishing mortality from these data. However, we would get a good estimate of the recruitment levels because there is good contrast in the relative abundance data (CPUE).

Doubleday method

Another more general approach to the catch-at-age method was put forward by DOUBLEDAY (1976). This method does not assume a linear relationship between the variables and is thus more difficult to calculate, as you need non-linear estimation methods. Its advantages are that fishing mortality **F** is not assumed proportional to effort, so it can be applied in the absence of effort data. However, this method also has the general problem that a good contrast is needed between fishing mortalities.

Table 8: Comparison of the Doubleday and Paloheimo methods (taken from HILBORN & WALTERS 1992 with permission)

Feature	**Paloheimo**	**Doubleday**
Computation	Linear, usually easy to solve	Non linear, requires a lot of computation; Potential problems with false minima
Recruitment estimation	Good, usually reliable for relative recruitment	Good, usually reliable for relative recruitment
Assumption about fishing mortality	F=Eq, requires effort data	None, can calculate age-specific vulnerabilities
Assumptions about natural mortality	M is constant over all years and ages	Can estimate different mortalities for all ages or times (in principle)
Ability to discriminate fishing from natural mortality	Requires major contrast in effort, generally poor	Requires contrast in F, generally poor

Other methods

An even more sophisticated and better method is that developed by FOURNIER AND ARCHIBALD (1982). Paloheimo and Doubleday derived their models as if they had an underlying deterministic process, but in nature everything is measured with error and has natural variability, which can be interpreted as noise. The method of Fournier and Archibald is very flexible and accounts for explicit estimation of errors in:

a) **C** the catch measurement,

b) **F** the fishing mortality,

c) **S/R** the stock recruitment relationship.

This method explicitly accounts for a stock recruitment relationship. It is very sophisticated both mathematically and statistically so it is not analysed here. It has the advantage that it can include several types of external information that can help in the estimation of parameters such as estimates of recruitment levels, fishing mortalities from other studies and effort data. METHOT (1989) developed this analysis further. It is even able to use CPUE, gear selectivity and independent survey biomass data in the estimation of parameters. Catch-at-age is currently the *state of the art* analysis for fisheries data.

CONCLUSIONS AND RECOMMENDATIONS

Fisheries stock assessment is not really a problem of the species or group we are analysing but rather a problem of the approach used. There are several methods available to perform stock assessment; some have been presented in detail. However, the important message to keep in mind is that there are three main pieces of advice for good stock assessment:

a) The data drives the analysis; although we should always try to do the best we can with whatever data we have, only complete and good quality data will provide us with reliable assessments. Having limited or imprecise data will provide only limited and uncertain advice no matter which models we use. The primary focus for shark stock assessment is not the model used, but the data required. For this reason fisheries managers should strive to build the necessary systems to collect the appropriate information for stock assessment.

b) There is no single ‘best’ model that should be used for fisheries stock assessment. The best assessment is one that uses **all** the models that can be applied to the available data. Results from all models should be compared and contrasted to detect inconsistencies, coincidences and patterns to obtain a complete picture. The results can then be used to improve the data and increase the capacity for better assessments in the future.

c) Stock assessment is a long-term, endless and dynamic process. It uses the models not only to decide how many fish we should take next year or how many fishermen we should allow to fish, but perhaps more importantly, to set goals for obtaining fisheries data, including biological and ecological information, to improve the quality of assessments. Fisheries stock assessment must be a feedback system in order to be successful.

PRACTICAL SESSION 1 - CALCULATING THE INTRINSIC REBOUND POTENTIAL OF SHARKS AND RAYS

Introduction

SMITH, AU and SHOW (1998) demonstrated that the usual demographic technique used to calculate the *intrinsic rate of increase* **r** of a population could be modified to estimate **r** using only five life-history parameters:

a) age at maturity = α

b) maximum reproductive age = **w**

c) adult instantaneous natural mortality = **M**

d) average number of female pups per adult female = **b**

e) survival to age of maturity = $\mathbf{l_x}$

This simplifies the data required to find **r** when complete information on reproductive output at each age is not known.

The authors also analysed how **r** changes in a population assuming that *adult* total mortality increases due to fishing, to a level of

$$\mathbf{Z} = 2\mathbf{M}$$

(approximately the mortality rate that would reduce the population to 50 % of its original size, this is accepted as the MSY level).

They then assumed that the population responds to this decrease in abundance with a density-dependent increase in the survival of young ages *up to the age of maturity*, which would compensate exactly for the increase in adult mortality. In fact, this assumption is not too wild as it is the same assumption implicit in stock-recruitment and surplus production relationships. Once the population has compensated for the increased adult **Z**, the adult survival is changed in the model to its original level (**M**) and the population increases again naturally. The resulting **r** is known as the *intrinsic rebound potential* ($\mathbf{r_{2M}}$).

This method allows us to examine and compare the relative ability of elasmobranchs species to recover from fishing pressure. As detailed in the original paper (SMITH et al. 1998), this method can be used to set some precautionary and very general management guidelines.

TASKS

Using the spreadsheet template published by SHOW (2000) and the user's manual provided, trainees will calculate the intrinsic rebound potential of a suite of species of sharks and rays. Trainees will then write a 2-3 page report summarising their findings and discussing the management measures they would recommend, if they were in charge of the stock assessment of the fisheries for these species.

The first step is to gather the necessary life-history parameters for each of the species. Trainees should use the database of biological information on fishes called ***FishBase***.

The life history parameters to be searched are:

a) Age at maturity = α

b) Maximum age = t_{max}

c) Maximum reproductive age = **w** (usually the maximum known age of the species)

d) Average number of female pups per adult female = **b**

e) Adult instantaneous natural mortality = **M**

Total mortality can be calculated using Hoenig's formula

$$Z = e^{(1.46 - 1.01(\ln tmax))}$$

by assuming that there is no fishery (i.e. no **F**) and all mortality is natural (**M**).

The following species may be analysed:

Squalus acanthias

Lamna nasus

Rhincodon typus

Mustelus manazo

Carcharhinus falciformis

Carcharhinus tilstoni

Sphyrna lewini

PRACTICAL SESSION 2 - FITTING A SURPLUS PRODUCTION MODEL TO CATCH AND CPUE DATA

Introduction

Surplus production models are probably the most widely used stock assessment models because of their simplicity and relatively low data requirements. Although these models were thought to be useless for shark stock assessment, they are now accepted for the assessment of other long-lived species with similar biology to sharks, such as marine mammals (PUNT 1991). In fact, it is now known that poor data quality is often the main problem for stock assessment rather than 'model inadequacy'. Surplus production models have been applied to sharks by a variety of authors. They have been used in the multi-species shark fishery of the east coast of the USA (OTTO et al. 1977, ANDERSON 1990, MCALLISTER et al. 1998), for the kitefin shark fishery (SILVA 1987) and in the Australian fishery for school and gummy sharks (XIAO 1995, WALKER 1999).

TASKS

Build a spreadsheet using the Schaefer surplus production model and fit the model (finding parameter values for the model) to the following data on catch and CPUE for the school shark (*Galeorhinus galeus*) fishery of Australia. See Table 9.

Table 9: Data from the School shark (*Galeorhinus galeus*) fishery in Australia (taken from WALKER 1995 with permission)

Year	Catch	CPUE	Year	Catch (tonnes)	CPUE	Year	Catch (tonnes)	CPUE kg/km of gill net
1930	11		1952	1298		1973	852	177
1931	18		1953	1609		1974	1161	246
1932	22		1954	2027		1975	1259	184
1933	216		1955	1377		1976	1367	163
1934	121		1956	1287		1977	1427	141
1935	214		1957	1697		1978	1346	120
1936	343		1958	2079		1979	1529	150
1937	410		1959	1734		1980	1989	124
1938	458		1960	2251		1981	2157	116
1939	541		1961	1917		1982	1935	110
1940	608		1962	2157		1983	1764	73
1941	902		1963	2119		1984	2445	108
1942	923		1964	2144		1985	2919	114
1943	1291		1965	2369		1986	3039	106
1944	1445		1966	2538		1987	2943	100
1945	1322		1967	3207		1988	2547	115
1946	1443		1968	3141		1989	2274	112
1947	1651		1969	3732		1990	2039	100
1948	1758		1970	3903		1991	2067	127
1949	1961		1971	3177		1992	1884	107
1950	1815		1972	2225		1993	1889	108
1951	1281							

Calculate biomass dynamics using the following equations:

$$C_t = qfB_t$$

where **q** is the catchability coefficient and **f** is the effort.

$$B_{t+1} = B_t + rB_t(1 - \frac{B_t}{K}) - C_t$$

Use the solver tool of Excel to estimate the parameters r, K and q. Solver is a routine to find answers to numerical problems, such as our non-linear estimation of parameters. Make sure to read the help menu of solver to understand how it works and what the different options mean. Make sure to check the box that makes solver show the results of each iteration. You may need to estimate an additional parameter Bo, the initial biomass at the beginning of the time series, unless you can safely assume that the fishery began with a virgin stock in 1973. Model fitting is achieved by using the above equations and catch data to estimate corresponding values of CPUE. The differences between the true values of CPUE (data) and those calculated with the above equations are minimized using solver to find the best values of the model parameters.

Build a graph of the true CPUE and the calculated CPUE to see how well the model fits the data. Once you have arrived to your best solution, use the parameters to calculate MSY (Maximum sustainable yield), $\mathbf{B_{MSY}}$ (stock or biomass level at MSY), and $\mathbf{f_{opt}}$ (or optimum effort, which should yield MSY). These are the numerical relationships to use:

$MSY = r K/4$

$B_{MSY} = K/2$

$f_{opt} = r/2q$

Once these values have been found were use them with the above equations to project the trajectory of population for the next 20 years if the fishing effort was MSY, 2 times MSY and ½ of MSY.

A discussion will be held to consider the problems obtaining a good fit to the data, what this means and why it happens, and the implications and consequences of advising managers to use the value obtained for MSY as a management regulation.

A practical report of at least four pages should be produced in the format of a scientific paper, including: Introduction, Objectives, Methodology, Results, Discussion, References.

PRACTICAL SESSION 3 - FITTING A DELAY-DIFFERENCE MODEL TO CATCH AND CPUE DATA AND ASSESSING UNCERTAINTY USING BAYESIAN ESTIMATORS

Introduction

The delay-difference model of DERISO (1980) is a smart simplification allowing the inclusion of biological information e.g. age structure to be taken into account in a simple format. It is an intermediate between surplus-production models and age-structured models.

The delay-difference models are biologically more realistic than surplus production models as they include terms for recruitment, natural and fishing mortality, and growth. However, like surplus production models, they can be simplified to be fitted to data on catch, effort and an index of abundance. The delay-difference model also requires knowledge of the increase in weight of the species and an estimate of natural mortality. It has not been used for the assessment of shark fisheries very often, but Monte Carlo simulations performed by BONFIL (1996) showed that the delay-difference model could be employed to estimate stock status of shark-like fishes and performed better than surplus production models. The model has also been used as part of the assessment of the school shark and gummy shark fisheries of Australia (WALKER 1999).

TASKS

Build a spreadsheet using the delay-difference model of Deriso and fit the model (find parameter values of the model) to the same data on catch and CPUE used in the previous practical exercise for the school shark (*Galeorhinus galeus*) fishery of Australia (Table 9).

Several things will have to be modelled at the same time for each year:

Biomass is modelled using the delay-difference equation:

$$B_t = (1+\rho)S_{t-1}\mathrm{B}_{t\text{-}1} - \rho S_{t-1}S_{t-2}\mathrm{B}_{t-2} - \rho w_{k-1}S_{t\text{-}1}\mathrm{R}_{t-1} + w_k\mathrm{R}_t$$

Given that we do not have information about the original biomass, we will assume that during the first year of exploitation the population was in virgin state, so we will use the estimate of **Bo** to model biomass in the first year. For the second year substitute $\mathbf{S_{t\text{-}2}}$ in the formula above for the value of ***S*** given below in the table of fixed parameters for school shark (Table 10). For all other years use the delay-difference formula.

For each year model the net survival that is the survival rate times the biomass left after removals (catch). This is done using the following equation:

$$Survival = S \cdot (1 - \tfrac{catch}{biomass})$$

The spawning (reproductive) biomass needed to calculate recruitment for the next year is simply the *biomass this year minus the catch this year*. Recruitment is calculated using the following equation (Beverton and Holt type of recruitment):

$$R_{t+1} = \frac{a \cdot Spawners_{t-k+1}}{b + Spawners_{t-k+1}}$$

However, for the first **k+1** years of recruitment (five years in the case of school sharks), assume that recruitment was as in the virgin population and use the following equation. It implies that recruitment at equilibrium is equal to numbers dying:

$$R_0 = \frac{B_0}{W_k}(1 - S)$$

Finally, calculate CPUE for each year as **q** times the biomass.

Use the solver tool in Excel to estimate the parameters **Bo**, **b** and **q**. Calculation of the stock-recruitment parameter (**a)** is avoided by assuming that the first recruitment was in equilibrium. A fixed point is obtained on the S/R curve that allows calculation of the value of **a**.

$$a = R_0 \frac{b + B_0}{B_0}$$

As in the previous exercise, model fitting is achieved using the above equations and catch data to estimate corresponding values of CPUE. The squared differences between the true and calculated values of CPUE (data) are minimised using solver to find the best values of the model parameters.

Table 10: Parameters for school shark

$S =$	0.896
$\alpha =$	1.31
$\rho =$	0.97
$W_k =$	4.29

Plot a graph of the true and calculated CPUE to see how well the model fits to the data.

Bayesian estimation of parameter uncertainty

The second part of this practical exercise involves learning how to evaluate the amount of uncertainty surrounding the parameter estimates. For any parameter combination (in the exercise, **b** and **B_0**), a Bayesian measure of the relative credibility (or likelihood of the observed data given **b** and **B_0**) is the "Kernel" **L** (**Bo**, **b**). This is given by the equation:

$$L\ (B_0, b) = SS^{-(t-1)/2}$$

Where **SS** is the sum of squared deviations between the observed and predicted observations (CPUE in our case) and t is the number of years of data in the sum of squares. The Bayes 'posterior probability' **p(Bo**, **b**) for any **Bo**, **b** is **L**(**Bo**,**b**) divided by the sum of all **L** values over all combinations of **Bo** and **b**.

Once part one (parameter estimation) is finished, set up a grid of **Bo** and **b** values (i.e. a table with **b** values as columns and **Bo** values as rows). Use the table function of Excel (under Data, table) to calculate **L** according to the above formula, at each grid point. Sum all these values and set up a second grid where the values in each grid point are the values from the first table divided by the total sum of all **L** values from the first table. Plot the values of the second table as a surface plot. This will show the spread of the probability of each **Bo** and **b** combination. The sum of all the columns is the 'marginal' probability of **Bo**, and the sum of all rows is the marginal probability of **b**. Plot these two marginal probabilities as simple line plots to see what the probabilities of each of these two parameters are alone.

Report

Prepare a report no less than 4 pages long from this practical session in the same form as in practical session 2 (i.e. in the format of a scientific paper including: Introduction, Objectives, Methodology, Results, Discussion, References). The problems encountered in finding sensible parameter values and the conclusions reached when looking at the Bayesian probability of the parameters **Bo** and **b** should be discussed.

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ANNEX I

LIST OF ACRONYMS

CAGEAN	Catch at age analysis
CPUE	Catch per unit effort
GEF	Global Environment Facility
IPOA	International Plan of Action for Conservation and Management
IRP	Index of relative production
ITQ	Individual Transferable Quota
LMR	Sustainable Use and Management of Living Marine Resources
MER	Maximum economic rent
MPA	Marine Protected Area
MSY	Maximum sustainable yield
PERSGA	The Regional Organization for the Conservation of the Environment of the Red Sea and Gulf of Aden
SAP	Strategic Action Plan
TAC	Total Allowable Catch
VBGM	von Bertalanffy growth model
VPA	Virtual population analysis
Y/R	Yield per recruit

ANNEX II

List of Participants at Course in April - May 2001

Name	Country	Institution	Duty station
Gamal Abd-Alhakeem Mohamed Hassan	Egypt	GAFRD	Hurghada
Galal Abu El-Wafa	Egypt	GAFRD	Hurghada
Mohamed Mohamed Ali Al-Wasief	Egypt	GAFRD	Sinai
Mohamed Abdu Abd Al-Rhaman	Egypt	GAFRD	Abu Ramad
Abd Al-Hamied Al-Rashash	Egypt	GAFRD	Suez
Ramadan Saied Abd Al-Latief	Egypt	GAFRD	Suez
Hasan Awad Mohamed	Egypt	GAFRD	Suez
Osman Darar Hasan	NW Somalia	Ministry of Fisheries	Berbera
Mohamed Yusuf Adam	NW Somalia	Ministry of Fisheries	Berbera
Ahmed Adam Madobe	NW Somalia	Ministry of Fisheries	Berbera
Abdulqadir Ismail Jama	NW Somalia	Ministry of Fisheries	Berbera
Saed Mohamed Hassan	NW Somalia	Ministry of Fisheries	Berbera
Bilal Said Mohamed	NE Somalia	Africa 70 / OTP (Fisheries Project)	Bosaso
Hussien Bile Ahmed	NE Somalia	Private Sector	Bosaso
Mohamed Abshir Mohamed	NE Somalia	Private Sector	Bosaso
Nur Haji Osman	NE Somalia	Africa 70 / OTP (Fisheries Project)	Bosaso
Ahmed Mohamed Shire	NE Somalia	Private Sector	Bosaso
Abdulkadir Said Ali	NE Somalia	Private Sector	Bosaso
Moussa Omer Yousouf	Djibouti	Environment Dept.	Djibouti
Nasser Ali Mahamoud	Djibouti	Fishing Training Centre, CFPP/Obock	Djibouti
Yusuf Ali Yusuf	Djibouti	Fisheries Dept.	Djibouti
Houssein Robleh Rirache	Djibouti	Environment Dept.	Djibouti
Omer Ahmed Al-Momani	Jordan	MSS/J.Univ.	Aqaba
Salim Nawaisa	Jordan	MSS/J.Univ.	Aqaba
Awad Ibrahim Hamza	Sudan	FRC	Port Sudan
Mohamed Abd El-Rahim Mohamed	Sudan	FRC	Port Sudan
Adam Edries Ahmed	Sudan	MFA	Port Sudan
Ahmed Mohamed Ahmed Al-Zahri	KSA	MAW/MFD	Qunfidah
Mahmoud Nasser Awaad	KSA	MAW/MFD	Umluj
Mohamed Soliman Hadad	KSA	MAW/MFD	Yanbu
Abdallah Moustafah Seraag	KSA	MAW/MFD	Jeddah
Omar Ahmed Al-Mahdawi	KSA	MAW/MFD	Leeth
Samir Mohamed Saleh	KSA	MAW/MFD	Jeddah
Shary Mohamed Mahmoud	KSA	MAW/MFD	Diba
Hussein Abdu Hussein Gaafar	KSA	MAW/MFD	Gizan
Soliman Mohamed Ghaseb	KSA	MAW/MFD	Gizan
Faisal Mohamed Al-Shoukany	KSA	MAW/MFD	Gizan
Yaser Taher Al-Kurashey	Yemen	MSRRC	Hodeidah
Mohamed Abdu Hamoud	Yemen	MSRRC	Mokah
Omer Mohamed Mazroa	Yemen	MSRRC	Al Khokah

Name	Country	Institution	Duty station
Ali Yusr	Yemen	MSRRC	Hajah
Ahmed Ali Osman	Yemen	MSRRC	Abyan
Husein Salem Husein	Yemen	MSRRC	Hodeidah
Mohamed Naser Ali	Yemen	MSRRC	Lahj
Khamis Ramasan Al-Akal	Yemen	MSRRC	Maharah
Faten Faisal	Yemen	MSRRC	Aden
Saied Rabie	Yemen	MSRRC	Hadramout
Saied Al-Akef	Yemen	MSRRC	Mukalla
Ahmed Kaed	Yemen	MSRRC	Aden
Mohamed Ahmed Al-Gullah	Yemen	MSRRC	Hodeidah
Mohamed Nasser Ali	Yemen	MSRRC	Lahj
Ali Ragieh Mohsein	Yemen	MSRRC	Lahj

MSS/J. Univ.	Marine Science Station / Jordan University
FRC	Fish Research Centre
MFA	Marine Fisheries Administration
MSRRC	Marine Science and Resources Research Centre
MAW/MFD	Ministry of Agriculture and Water / Marine Fisheries Department
GAFRD	General Authority for Fish Resources Development

List of Participants at Course in April 2002

Name	Country
Abdillahi Omar Farah	Djibouti
Abdoulkader Ahmed Aouled	Djibouti
Marouf A. Karim Khalaf	Jordan
Farouk Alaa Al-Din Arsilan	Jordan
Talal Abu Shousha	Saudi Arabia
Laffy Sa'id Saad Al-Selmy	Saudi Arabia
Hussein Ahmed Al-Nazary	Saudi Arabia
Hassan A. Hamid Ghostainia	Saudi Arabia
Samaron Omar Gaddi	Somalia
Abdulkadir Said Ali	Somalia
Ahmed Abdallah Yassin	Somalia
Mohamed Abshir Mohamed	Somalia
Iqbal Sayed Ahmed	Sudan
Abdallah Naser Al-Awady	Sudan
Zaki Mohamed Ali	Yemen
Murtada Ahmed Elwan	Yemen
Fadel A. Allah Mohd. Al-Fakhih	Yemen
Anuar Fissal	Yemen
Hashim Al-Sakaf	Yemen
Ahmed Farag bin Waber	Yemen
Saleh Kassem	Yemen
Fath Saleh Al-Jabil	Yemen
Saeed Shaher Saeed	Yemen

ANNEX III

FINAL QUIZ

PERSGA

Course on Stock Assessment of Shark and Ray Fishery Resources

Final Quiz

Full Name______________________________

Country___________________________

Part I

Circle the correct answer (only one) for each of the following questions:

1- The main objective of stock assessment is:

a) to find MSY
b) to make quantitative predictions needed for management
c) to find the parameters of the model that is being used

2- The main objective of fisheries management is:

a) to obtain maximum economic rent
b) Conservation of fishery resources
c) Objectives depend on several considerations that change from case to case

3- Which of the following is a surplus production model:

a) VPA
b) Fox model
c) Life tables

4- The intrinsic rate of increase of a population depends on great part on the following:

a) the characteristics of the fishing gear
b) the stock-recruitment relationship
c) the balance between reproduction, body growth and natural mortality
d) the abundance of the stock

5- The total mortality rate of a stock can be estimated by the following method:

a) Schaefer surplus production model
b) Catch curve
c) Delay-difference model

6- Which of the following is a formula representing the net rate of total mortality:

a) $1-e^{-F}$
b) e^{-Z}
c) $(1-S)$

7- Which of the following are data needed to use a surplus production model to assess a stock:

a) time series of catch and effort, and an estimates of Bo
b) time series of catch, effort, and recruitment strengths
c) natural mortality rate, and catch at each age

8- The best way to perform stock assessment is by:

a) Using the CAGEAN method of Archibald and Fournier (1982)
b) Using the Delay-difference method of Deriso (1980)
c) Using all available methods we can apply and comparing their results to check the consistency of our assessment

9- One of the main problems for performing assessment with any model is:

a) Not having enough information on the biological processes of the stock
b) The contrast on the data that is used for the assessment
c) The overexploitation of the resource

10-The yield per recruit model of Beverton and Holt is based on the following:

a) Time series of catch and effort and estimates of M
b) The logistic model of population growth
c) The von Bertalanffy growth model, the exponential survival equation and the general yield equation

Part II

Answer the following questions giving a complete discussion of each of the topics. Use as much space as you need.

1- If you have made a stock assessment for a shark species and your results from several models indicate that there is large uncertainty about the status of the stock what would be the advice you would give to the managers?

2- Describe at least one way in which you could estimate the amount of uncertainty in the parameters of a delay-difference model when you apply it to data from a fishery.

3 – Discuss in detail: a) what is the situation of fisheries data for sharks and rays in your country of origin, b) include your opinion of which stock assessment methods could be used at the moment given the existing data, and c) suggest ways in which your government could improve the collection of data in order to perform a good stock assessment of the shark resources of your country.

Answers to Multiple Choice Questions:

1-	b
2-	c
3-	b
4-	c
5-	b
6-	c
7-	a
8-	c
9-	b
10-	c