UNIT THREE

FISH POPULATION DYNAMICS, EXPLOITATION, & THREATS

Unit 3: Pop. Dyn., Explotation, Threats.: ILOs.

At the end of this unit *students will*

- know what the basics of fish *population dynamics* is & understand the factors which influence it;
- know some key *terms* & *concepts* associated with population dynamics & fisheries;
- know & understand the *concept of fisheries exploitation* & its *implication* for *fisheries stock management*.
- know & understand some *measures* adopted for dealing with *overexploitation* of fisheries.

Unit 3, 1: Population dynamics & Fisheries Terms & Concepts

Unit 3: Pop. Dyn.: Terms & Concepts

- *Fishery* – an area with an associated *fish* or *aquatic population* which is harvested for its commercial or recreational value.

- E.g. of commercial fisheries - wild fisheries & fish farms.

- Thus, it involves raising & harvesting fish & other aquatic organisms in freshwater, oceans, & *farms*.

Unit 3: Pop. Dyn.: Terms & Concepts

- *Population dynamics?*

- It involves the fish population changes & the factors responsible for these fluctuations over *time* & *space*.

- It is the basis for understanding changing fishery patterns, habitat destruction, predation, optimal harvesting rates, etc.

Unit 3: Pop. Dyn.: Terms & Concepts

- Thus, *population dynamics of fisheries* is used by fisheries scientists to determine sustainable yields.

- The basic accounting relation for population dynamics is the *BIDE* model:
  - ***B***irth,
  - ***I***mmigration,
  - ***D***eath,
  - ***E***migration

Unit 3: Pop. Dyn.: Terms & Concepts

$$N_1 = N_0 + B - D + I - E$$

- where
  - N_1 = number of individuals at time 1,
  - N_0 = number of individuals at time 0,
  - B = number of individuals *born*,
  - D = number of individuals that *died*,
  - I = number of individuals that *immigrated*, &
  - E = the number that *emigrated* between time 0 & time 1.

Unit 3: Pop. Dyn.: Terms & Concepts

- While *immigration* & *emigration* can be present in wild fisheries, they are <u>usually not measured</u>.

- Thus, a fishery population is assessed by estimating 3 dynamic rate functions, viz:
  - *birth rate*
  - *growth rate*
  - *mortality rate*

Unit 3: Pop. Dyn.: Terms & Concepts

- These rates if measured at different time intervals, gives the *harvestable surplus* - <u>number of fish that can be harvested without affecting long term stability</u>.

- The harvest within the harvestable surplus is called *compensatory mortality* i.e. harvest here is substitute for deaths that would otherwise occur naturally.

- Harvest beyond this is *additive mortality* i.e. harvest in addition to natural death of fish.

Unit 3: Pop. Dyn.: Terms & Concepts

- *Life history of a fish* is the descriptive account of the complete life cycle of a fish.
- This together with stock size, must be understood before sensible *planning* can be done in fisheries mgt
- A population contains unique & dynamic attributes e.g. *birth* & *death rates*, *age structure*, *gene pool*, etc.

Unit 3: Pop. Dyn.: Terms & Concepts

- These attributes, shaped by the env't constitute the *life-history traits* which determines the *resistance* of the population to external disturbance & stress.

- Life history involves an understanding of phases fish populations pass, i.e. from *birth* to *maturity*.

- This includes survival, mortality rate, fecundity, & life span duration coupled with *env'tal conditions*.

Unit 3: Pop. Dyn.: Terms & Concepts

- The full set of this information provides
  - a <u>complete description</u> of the the *population ecology*, &
  - also enable one to deduce the <u>controlling factors</u>
- These help population ecologists to determine the *population dynamics* of a stock.

Unit 3: Pop. Dyn.: Terms & Con.: Birth rate

- Also called *recruitment*, it usually refers to the age a fish can be caught & counted in fish nets.

- It is the number of new young fish that enter the exploitable stock of a population in a given year due to growth &/or migration.

- Fish population size can fluctuate widely & 5 to 10-fold variations in abundance are usual.

Unit 3: Pop. Dyn.: Terms & Con.: Birth rate

- Thus, variations in *reproductive* & *recruitment* success are prime factors behind changes in abundance.

- Yearly variations in abundance often seem random, & success in recruitment often has a poor relationship to adult stock levels & fishing effort.

- Thus, the recruitment problem is that of predicting the number of fish *larvae* in one season that will survive & become *juvenile* fish in the next season.

Unit 3: Pop. Dyn.: Terms & Con.: Birth rate

- It is described as '*the central problem of fish population dynamics*' & '*the major problem in fisheries science*'.
- That is, fish produce huge volumes of larvae, but the volumes are very variable & cumulative mortality is high.
- This makes good stock prediction difficult.

Unit 3: Pop. Dyn.: Terms & Con.: growth rate

- Fish *grow* throughout their lives & hence growth is an intensively studied aspect of fish biology.

- Growth is defined as the change in size (*length* &/or *weight*) over time.

- OR, the change in biomass due to change in numbers from *recruitment* & *mortality* & increment in weight or length.

Unit 3: Pop. Dyn.: Terms & Con.: growth rate

- There are 2 types of growth:
  - population growth in numbers or weight
  - individual growth in length or weight

- *Population growth* depends on the combined effects of natality (birth rate), mortality rate, & migration.

- When weight is considered, population growth also depends on sum of individual growth increments.

Unit 3: Pop. Dyn.: Terms & Con.: growth rate

- *Individual growth* is genetically determined but, it is affected by several factors:
  - food availability (quality/quantity);
  - temperature (fish are poikilotherms);
  - variable allocation of surplus energy (somatic or gonadal tissue growth; locomotion & maintenance);
  - sexual differences;
  - density & size distribution (hierarchical behaviour &/or competition); etc

Unit 3: Pop. Dyn.: *Approaches to growth est.*

- Growth rates of fishes are either measured directly or predicted by several methods:
  - *Direct observations* from experiments of either confined or tagged/recaptured wild fish.
  - *Length-at-age data* - with precise & valid age estimation & large unbiased random sample (most satisfactory).
  - *Back calculations from analysis of hard parts*, using ratios between fish lengths & growth zone spacing.

Unit 3: Pop. Dyn.: growth parameters

- There are several different definitions of growth which can be expressed as rates e.g. include:
  - *absolute growth rate*
  - *relative growth rate*
  - *instantaneous growth rate*

- The simplest assumes a linear growth rate within the time interval of concern $[t_1, t_2]$.

Unit 3: Pop. Dyn.: *growth parameters*

- a) *Absolute growth rate*: change in weight/length per unit time, usually a year.

- where W_1 = weight at time 1, W_2 = time at time 2

$$g(t) = \frac{W_2 - W_1}{t_2 - t_1} = \frac{\Delta W}{\Delta t}$$

Unit 3: Pop. Dyn.: *growth parameters*

- b) *Relative growth rate*: change in weight/length per unit time relative to start value in percent.

- where W_1 = weight at time 1, W_2 = time at time 2

$$g(t) = \frac{\frac{W_2 - W_1}{t_2 - t_1}}{W_1} \cdot 100$$

Unit 3: Pop. Dyn.: growth parameters

- c) *Instantaneous growth rate* is the proportion by which a population would grow in a very short period of time (< 1yr) & can be expressed as,

$$G = \frac{\ln(W_2) - \ln(W_1)}{t_2 - t_1}$$

- where W_1 = weight at the time 1, W_2 = time at time 2

- When multiplied by 100, it is called the *specific growth rate*.

Unit 3: Pop. Dyn.: *growth & recruit. Regulat.*

- A number of *hypotheses* have been formulated to explain variations in wild **adult fish** abundance.
- These are mainly due to differences in recruitment & growth of young fish.
- None is mutually exclusive & they include:
  - *starvation, predation, advection, & growth* hypotheses.

Unit 3: Pop. Dyn.: *growth & recruit. Regulat.*

- *Starvation hypothesis* - if there isn't enough plankton food in the water, larval fish mortality will increase & few, if any, will survive to become adults.

- This concerns the critical phase in a fish's life just after hatching when young larvae still have the remnants of the yolk sac on which to subsist.

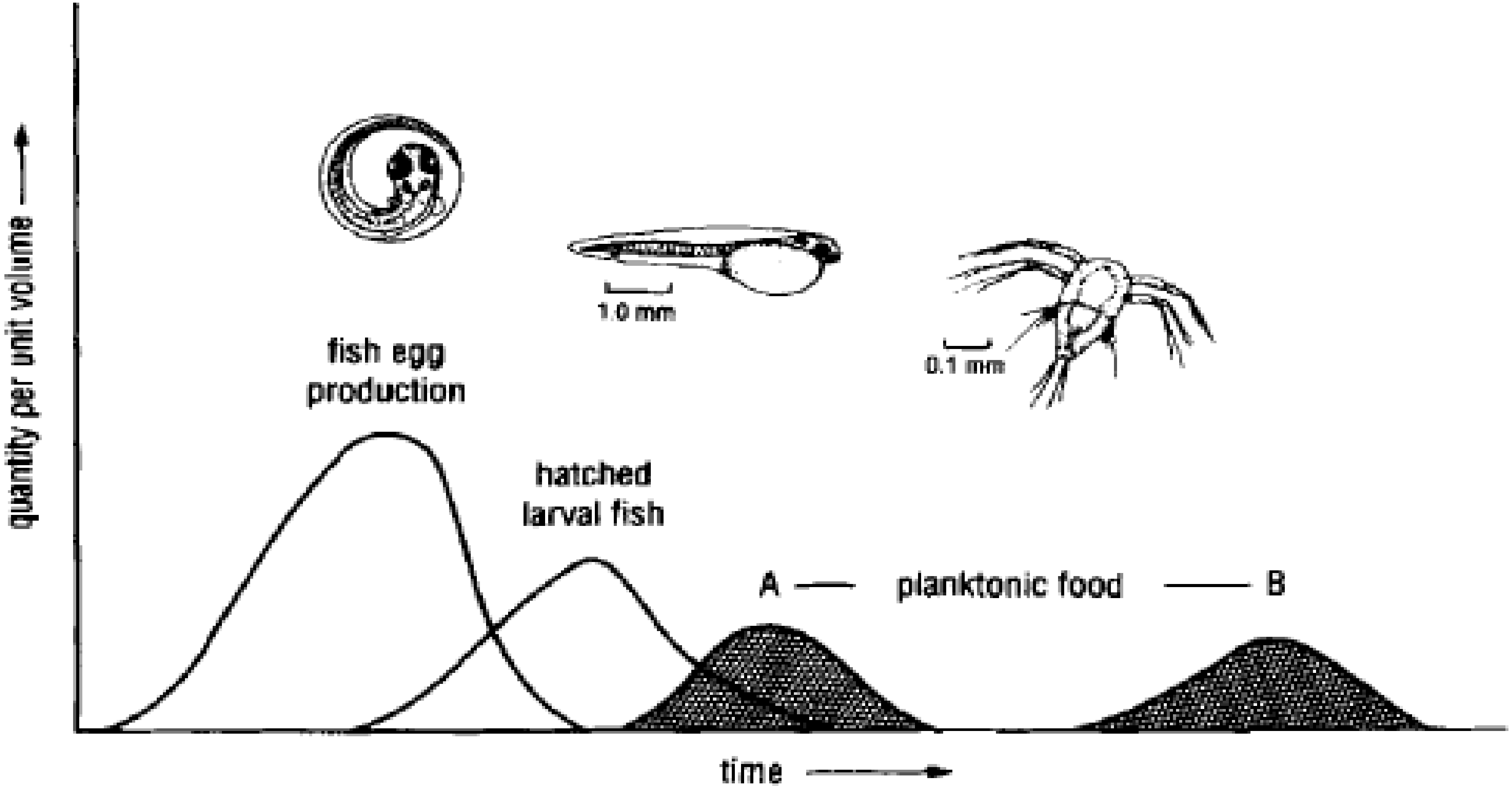
- To survive, larvae must begin to eat sufficient planktonic food before the yolk finishes.

Starvation hypothesis (cont)

- This means that the larvae must hatch at a time in phase with abundant plankton concentrations.

- If a larval fish hatches too **early**, or too **late**, relative to its planktonic food supply, it will die….

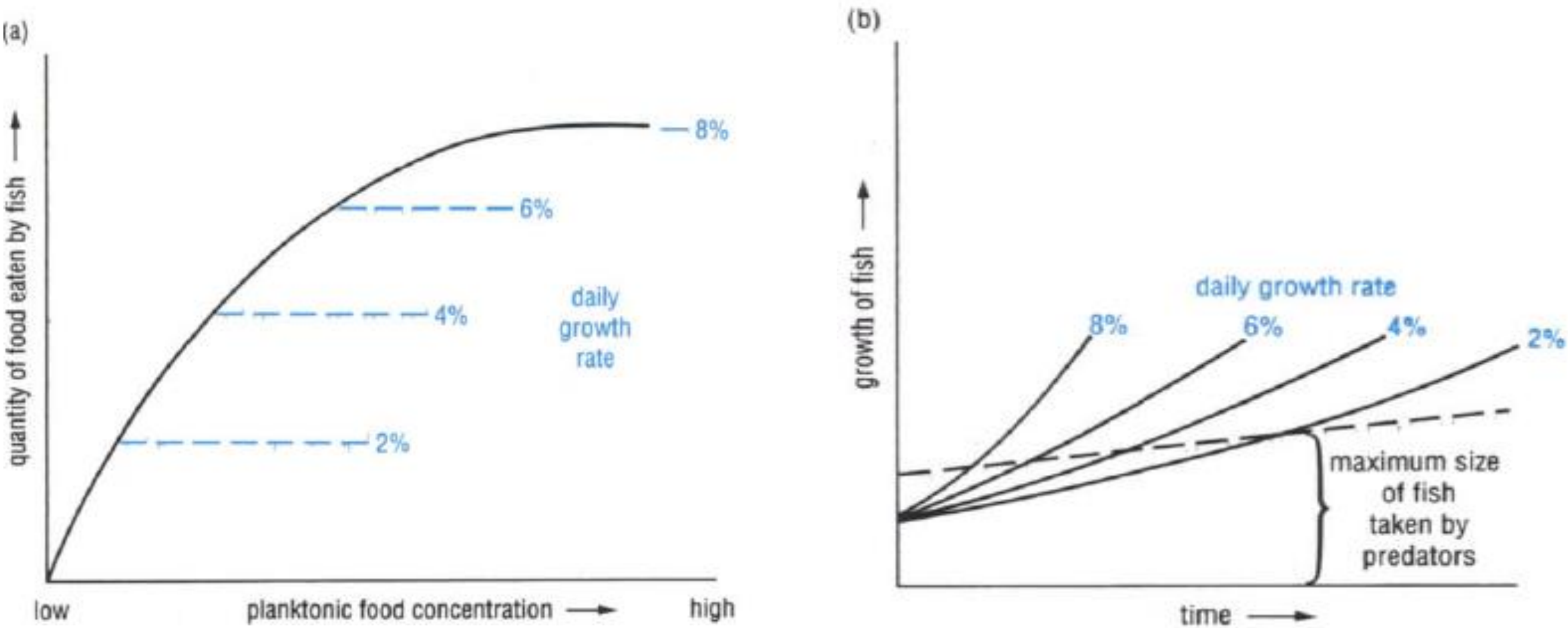
Unit 3: Pop. Dyn.: *growth & recruit. Regulat.*



Unit 3: Pop. Dyn.: *growth & recruit. Regulat.*

- In the *predation hypothesis*, predators may consume large numbers of both larval & juvenile fish.
- Heavy predation results in few young surviving to become adults.
- Juveniles that grow slowly are exposed to longer predation times & lower survival than fast-growing ones….

Unit 3: Pop. Dyn.: *growth & recruit. Regulat.*



Unit 3: Pop. Dyn.: *growth & recruit. Regulat.*

<u>*Predation hypothesis* (cont)</u>

- It assumes that larger organisms have fewer predators & are better at escaping predation.

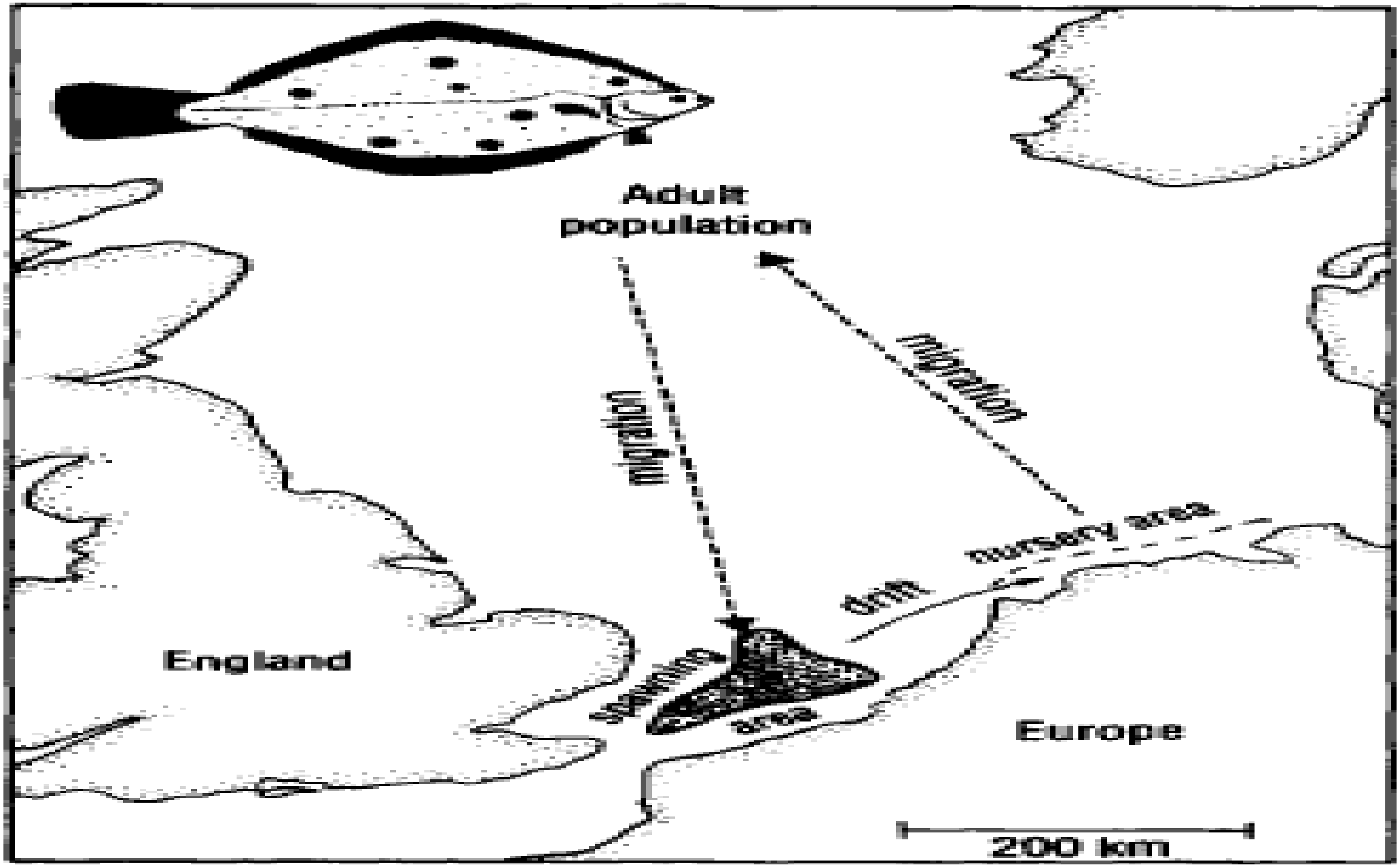
- So, larval/juvenile fish that grow faster, reduces mortality & more fish survives & vice versa.

- It is partly dependent on *planktonic food supply*, but here amount of food is not restricted to the critical phase….

Unit 3: Pop. Dyn.: *growth & recruit. Regulat.*

- In the ***advection hypothesis***, it is assumed that physical processes may move young fish from nursery areas to unfavourable ones where they can't survive.
- It can be illustrated in a number of different ways depending on the type of fish species.
- E.g. plaice spawns on specific sites linked to nursery sites to which larvae are carried by currents..

Unit 3: Pop. Dyn.: *growth & recruit. Regulat.*



Unit 3: Pop. Dyn.: *growth & recruit. Regulat.*

Advection hypothesis (cont)

- But in some years, strong storm activity may disrupt the current system that carries larval fish to these suitable nursery areas.

- When this happens, larvae may be taken to less favourable areas & may not survive.

Unit 3: Pop. Dyn.: *growth & recruit. Regulat.*

- The *growth hypothesis* is based on the fact that fish growth is inhibited by either biotic (e.g. food, etc) or abiotic (e.g. temperature, etc) factors.

- **Note**: the product of the maximum size fish attains at harvest time & the number of fish captured, gives the *biomass yield* to the fishery.

- Size & number of fish are also used to establish fish *quotas* in terms of allowable tonnage.

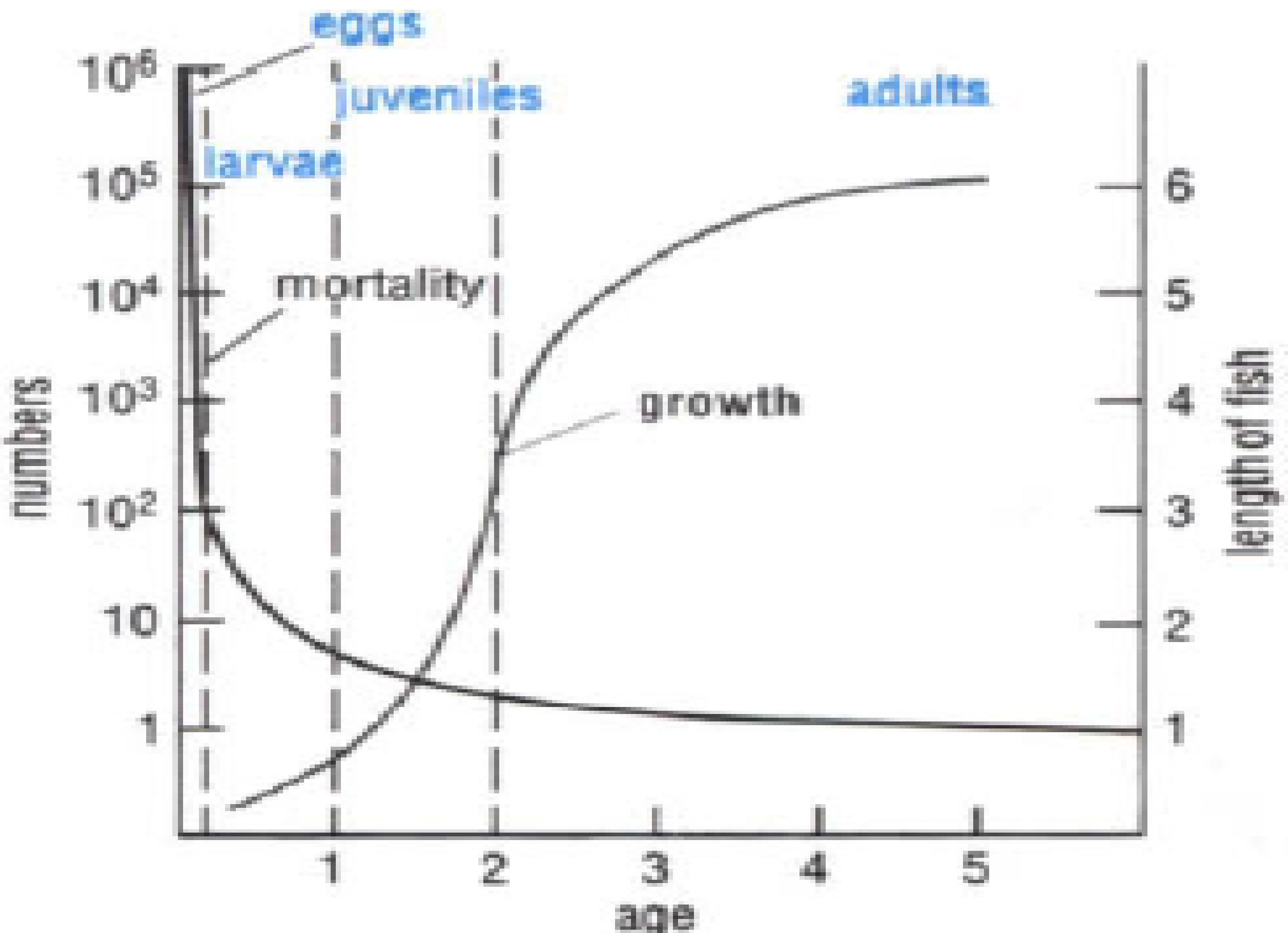
Unit 3: Pop. Dyn.: *growth & recruit. Regulat.*

Growth hypothesis (cont)

- *Numbers* are determined by survival, & *size* is determined by growth.

- The growth hypothesis is derived from the growth curve…

Unit 3: Pop. Dyn.: *growth & recruit. Regulat.*



Unit 3: Pop. Dyn.: *growth & recruit. Regulat.*

Growth hypothesis (cont)

- Growth is dependent on a variety of factors that affect growth rate & the size (length) at maturity.

- E.g. growth rate & *temperature* are directly related but size at maturity & temperature are inversely related.

Unit 3: Pop. Dyn.: *growth & recruit. Regulat.*

Growth hypothesis (cont)

- So, temperature increase can have dual effect of producing more rapidly growing fish, but ones that are smaller at maturity.

- Also, fish growth efficiency varies with type of food consumed e.g. prey with high protein content produce faster growth than foods with very high water content & low protein.

Unit 3: Pop. Dyn.: *growth & recruit. Regulat.*

Growth hypothesis (cont)

- Again, growth is also influenced by the metabolic costs associated with particular types of prey.

- Thus, as prey type changes (due to changes in the ecosystem), the growth efficiency of fish will also change, & this will affect the growth curve.

Unit 3: Pop. Dyn.: *growth & recruit. Regulat.*

- Each of the 4 hypotheses can be shown to have some exp'tal support for changes in fish abundance.

- Hence, more than one mechanism is involved.

- Other possible factors e.g. *fish disease*, may at times be important in regulating recruitment of young to adult stocks.

Unit 3: Pop. Dyn.: *growth & recruit. Regulat.*

- To improve the fisheries mgt, these mechanisms need more *research* through experimentation, field data, & ecosystem models.

Unit 3: Pop. Dyn.: (c) mortality

- *Mortality* is a parameter used in fisheries population dynamics to account for loss of a fish stock by death
- It includes *harvest mortality* & *natural mortality* which includes non-human predation, disease & old age.
- In contrast to *growth* & *reproduction*, which can be considered as individual-based processes, *mortality* is often applied or assessed at the population level.

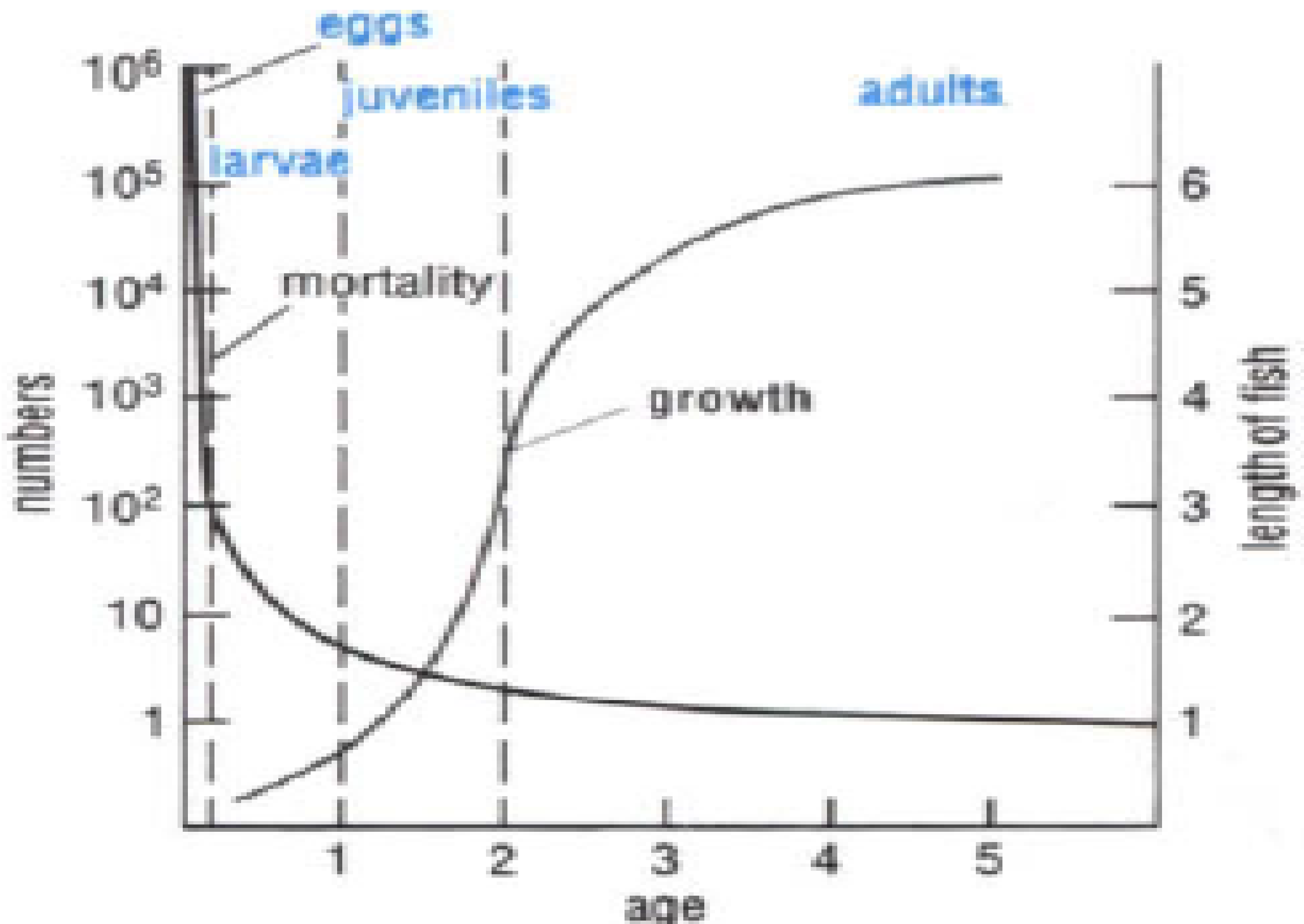
Unit 3: Pop. Dyn.: (c) mortality

- Mortality rates are used when describing fish death.

- The <u>chance of dying</u> as a function of *time* is closely related with env'tal <u>predictability</u>.

- Events that cause variation in *year-class* strength in fish occur during the 1st year of life & hence it is the youngest stage that suffers most of the mortality…

Unit 3: Pop. Dyn.: (c) mortality



Unit 3: Pop. Dyn.: (c) mortality

- Thus, mortality rates are size-specific, being highest at the *egg* & *yolk-sac* stages & declining thereafter..

- In stock assessment, mortality rates are considered only for adult population, where variations are much less.

- Of fisheries assessment import, is the level of fishing mortality that affects stock compared to natural mortality.

Unit 3: Pop. Dyn.: (c) mortality

- Factors contributing to mortality are divided into 2 main categories, viz – *abiotic* & *biotic* factors:

  - Abiotic factors **(**physicochemical env’t)
    - **Temperature**
    - **Salinity**
    - **Oxygen**
    - **Light**
    - **Stability & disturbances**
    - **Pollution**

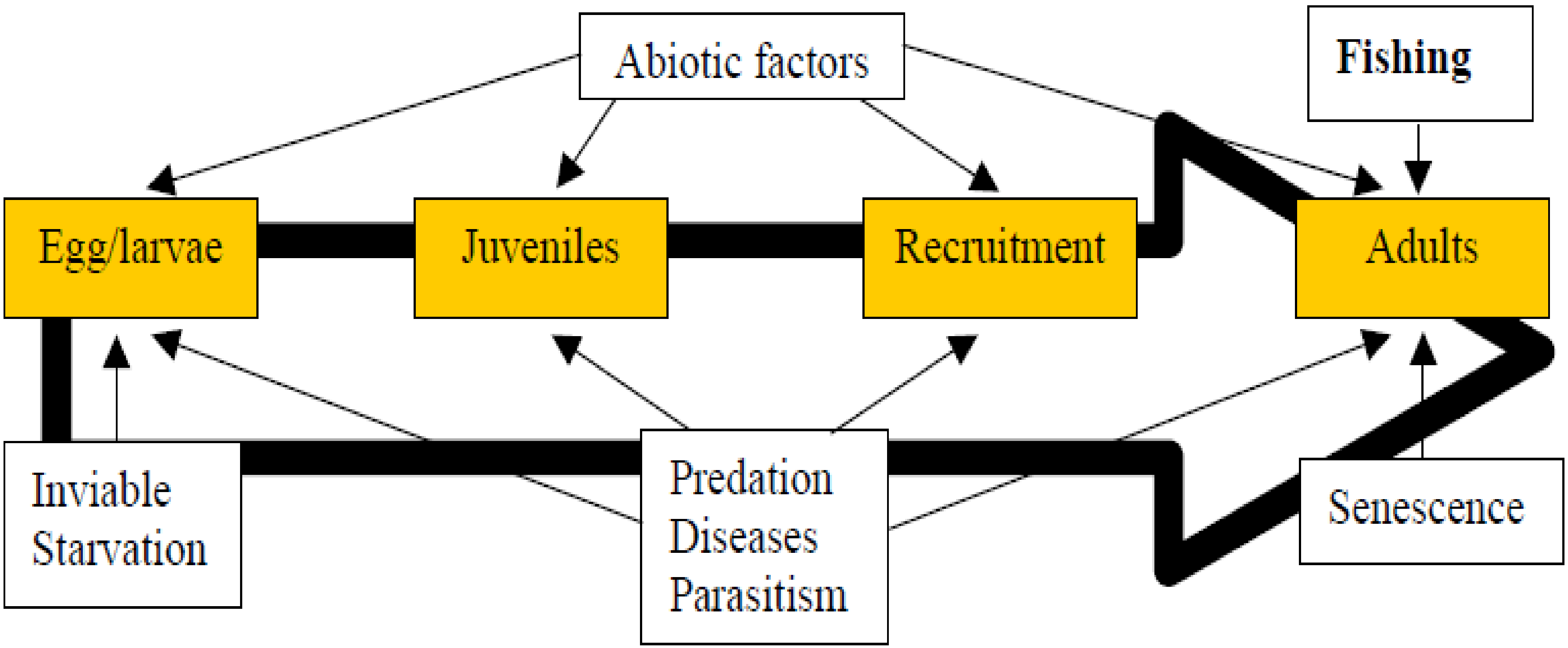
Unit 3: Pop. Dyn.: (c) mortality

- Factors contributing to mortality are divided into 2 main categories, viz – *abiotic* & *biotic* factors:

  - Biotic factors (other organisms)
    - **Predation**
    - **Cannibalism**
    - **Density**
    - **Starvation**
    - **Competition**
    - **Diseases**

Unit 3: Pop. Dyn.: (c) mortality

- Each of these factors has relative importance at various stages in the life cycle of fishes.



Unit 3: Pop. Dyn.: (c) mortality

- Generally, predation is considered the most important natural factor at the *larval stage* & older.

- Fishing mortality is the most important factor for the *adult* stages & often surpass non-human predation for heavily fished stocks.

Unit 3: (c) quantitative mortality measures

- Over a time interval, a portion of fish alive (N_1) at beginning of time interval (t_1) will die by natural or fishing causes, while the rest will survive (N_2) till end of the time interval (t_2).

- This can be mathematically expressed as:

$$N_1 = P + D + O + C + N_2$$

- P, D, O = # of fish dying of *predation*, *diseases*, & other *causes*, & C = numbers caught by *fishing*.

Unit 3: (c) quantitative mortality measures

- There are 2 ways of expressing mortality:
  - *relative mortality* & *instantaneous mortality*

- a) <u>relative mortality</u> *(Z)* represents mortality as a fraction/percentage of the initial number (N) over a time interval [t_1, t_2] defined as:

$$Z(t_1, t_2) = \frac{N(t_1) - N(t_2)}{N(t_1)}$$

Unit 3: (c) quantitative mortality measures

- The closely related quantity, **survival**, is defined as:

$$S(t_1, t_2) = 1 - Z(t_1, t_2) = \frac{N(t_2)}{N(t_1)}$$

- *S* is the ratio between the numbers of individuals present at time t_2 & the initial number at time t_1.

- The possible values of *mortality* & *survival* are from **0** to **1**, or if expressed in percentages, from **0** to **100**.

Unit 3: (c) quantitative mortality measures

- b) Instantaneous rate of fishing mortality (*F*) is the fraction of average fish population taken by *fishing*.

- It is the rate at which fish are dying due to fishing, & is expressed per unit time.

- It usually applies to rates applied over a very short period of time (*dt*), where numbers don't change much.

Unit 3: (c) quantitative mortality measures

- It is assumed that #s dying from one cause aren't affected by numbers dying from any other cause.

- Hence, a decrease in the population size can then be considered as proportional to the total mortality coefficient ***Z*** & written as:

$$\frac{dN}{dt} = -Z \cdot N_t$$

Unit 3: (c) quantitative mortality measures

- Integrating this equation, one obtains:

$$\ln(N_t) = -Z_t + \textbf{constant}$$

$$N_t = N_0 \cdot e^{-Zt}$$

where N_0 = numbers alive at time $t = 0$.

- This is the traditional model for describing mortality in a fish stock (<u>fishing</u> or <u>natural causes</u>), also called *exponential decay model*.

Unit 3: (c) quantitative mortality measures

- In this form, the total mortality ***Z***, is the sum of all the other coefficients, so that;

$$Z = F + M$$

where, ***F*** = instantaneous rate of fishing mortality & ***M*** = natural mortality

Unit 3: Pop. Dyn.: Other concepts & terms

- *Fishing effort (f)* is total time spent fishing or total # of gears used for specific period of time in a particular place for fishing & is expressed severally depending on the situation; e.g.
  - # of **boats deployed**,
  - # of **fishermen working**,
  - # of **boat-days or time spent fishing**,
  - # of **meters of gill-net set**,
  - # of **hooks set**,
  - # of **pulls** or **shots made**, etc.

Unit 3: Pop. Dyn.: Other concepts & terms

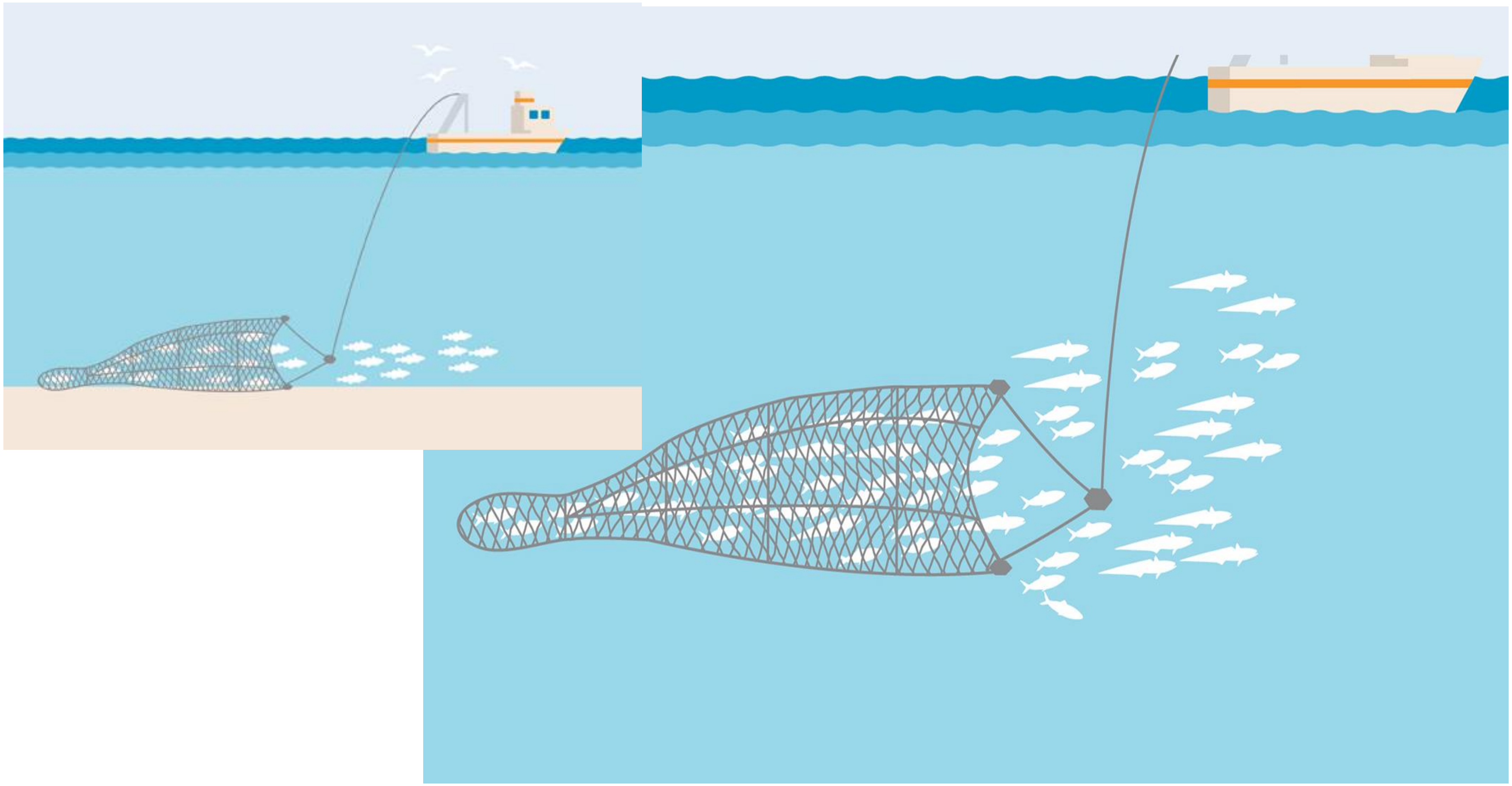
Fishing effort (cont)

- A good measure of f will be proportional to the amount of fish captured but different measures are appropriate for different kinds of fisheries.

- E.g., f exerted by a fishing fleet in a *trawl fishery* might be measured by;…
  - *summing* the products of the engine power for each boat & time it spent at sea OR

$$= \text{KW} \times \text{days}$$

Unit 3: Pop. Dyn.: Other concepts & terms



Trawl net fishing

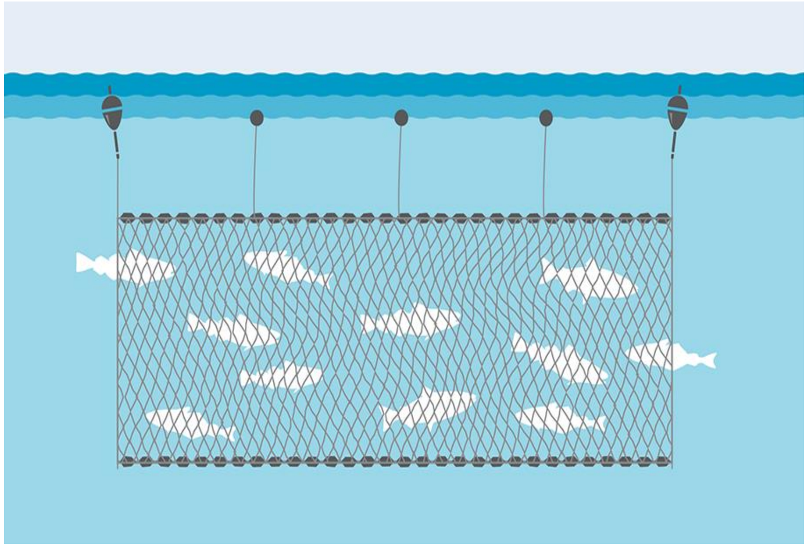
Unit 3: Pop. Dyn.: Other concepts & terms

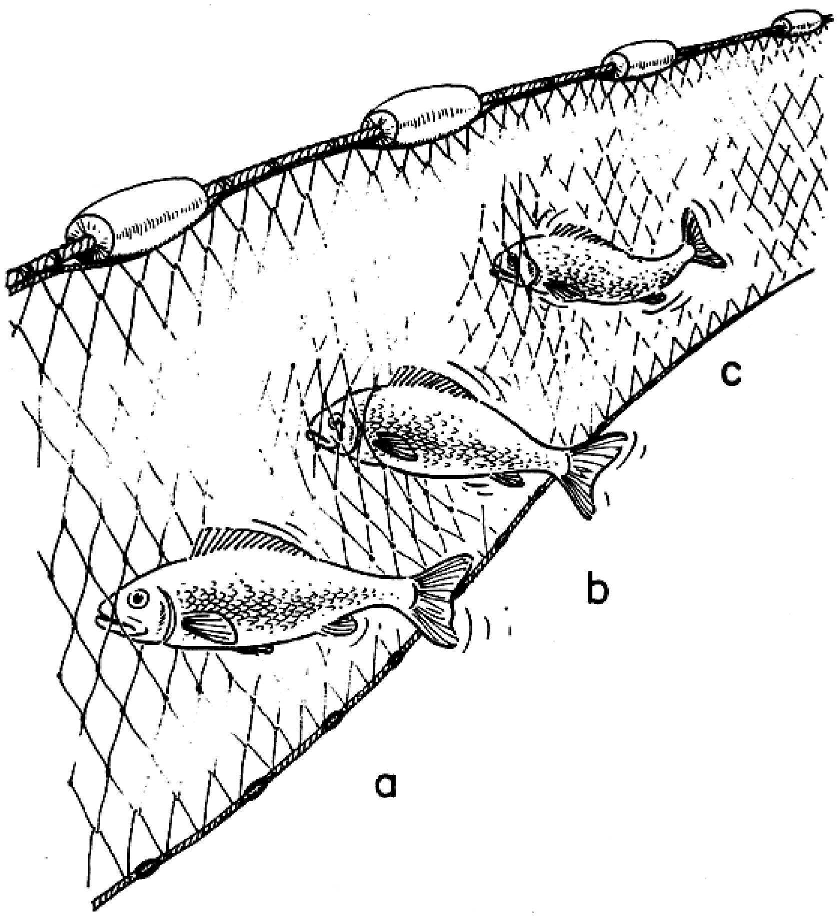
Fishing effort (cont)

- For a *gill-net fishery* the *f* might be measured by
  - *summing* the products of the length of each set net & the time it was set in the water (Km × soak time)….

- In fisheries where boats spend a lot of time looking for fish, a measure based on search time may be used.

Unit 3: Pop. Dyn.: Other concepts & terms





Gill net fishing

Unit 3: Pop. Dyn.: Other concepts & terms

- Estimates of *f* is essential for estimating *fishing intensity* or nominal fishing effort.

- This is the fishing effort per unit area expressed mathematically as;

Fishing Intensity = **f/A**, where A is the area

Unit 3: Pop. Dyn.: Other concepts & terms

- *Population size* (*N*) refers to a group of fish of the same species alive in a defined area at a given time.

- *Overpopulation* indicates any case in which the population of any fish species exceeds the carrying capacity (*K*) of its ecological niche.

- In fisheries biology, K is maximum fish population that can exist in the absence of commercial fishing.

Unit 3: Pop. Dyn.: Other concepts & terms

- *How can the population size of a fishery be estimated?*
- It's impossible to count every single fish so fish population size (N) is often estimated by <u>sampling</u>.
- One way to sample is to count all individuals in a <u>few representative areas</u>, & then <u>extrapolate</u> to the total # of individuals likely in the entire range.

Unit 3: Pop. Dyn.: other concepts & terms

- But, this method only works well if samples are representative of overall density of the population.
- A 2nd method to estimate *N* for mobile animals like fish is the *mark-recapture* method.
- Here, a certain # of individual fishes are captured & tagged or marked (M), then released back & allowed to mingle with the rest of the population.

Unit 3: Pop. Dyn.: other concepts & terms

- After a certain period, a 2nd sample is taken (**R**).
- The assumption is that, the marked individuals (**M**) are <u>well dispersed</u> in the population & <u>haven't suffered increased mortality</u> from the 1st capture.
- So, the ratio of marked to unmarked individuals in the 2nd capture should reflect ratio of marked to unmarked individuals in the <u>entire population</u>.

Unit 3: Pop. Dyn.: other concepts & terms

- Hence, an estimate of N can be obtained using:

$$\mathbf{M/N = m/R}$$

$$\mathbf{N = \frac{m/R}{M}}$$

- **N** = population size; **M** = # of fish captured & marked in 1st sample; **R**= # of fish captured in resampling event; **m**= # of "R" that were already marked

Unit 3: Pop. Dyn.: other concepts & terms

- For this equation to provide reasonable ***N*** estimates, the following assumptions must be met:
  - 1) natural mortality & vulnerability to fishing gears of tagged & untagged animals should be the same;
  - 2) tagged fish should be randomly distributed in the population;
  - 3) tags should not be lost;
  - 4) there should be no migration into or out of stock;
  - 5) all tagged fish should be reported, etc

Unit 3: Pop. Dyn.: other concepts & terms

- *Minimum Viable Population* (MVP) is the smallest *N* at which fish can exist without facing extinction from natural disasters, demographic, env'tal, or genetically random events.

- Unsustainable fisheries can drive a fish population to MVP & can potentially cause extinction.

Unit 3: Pop. Dyn.: other concepts & terms

- *Fish stock* is a subset of <u>one particular species</u> with the same demographic parameters (e.g. growth, natality, & mortality) & inhabiting a defined geographical area.

- A unit stock has several <u>key features</u>:
  - are large enough,
  - are basically self-reproducing,
  - abundance changes is not dominated by migration, &
  - population show similar patterns of <u>growth</u>, <u>mortality</u>, <u>migration</u> & <u>dispersal</u>

Unit 3: Pop. Dyn.: other concepts & terms

- A *sub-group* of species can be treated as a stock if possible differences in the group & interchange with other groups can be ignored.

- Practically, stock size is mainly assessed by quantity of landings, which is principally a function of the *N*, *fish spatial variability*, & *f*.

Unit 3: Pop. Dyn.: other concepts & terms

- *Age* is # of years completed/attained by a fish & it can be expressed with Roman or Arabic letter.

- It can be determined by counting growth rings in
  - *scales*,
  - *otoliths*,
  - *fin spines* (cross-sections)
  - *teeth*
  - *cleithrum*

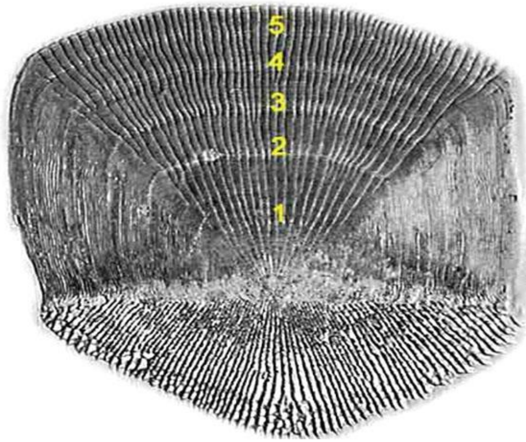
Unit 3: Pop. Dyn.: other concepts & terms

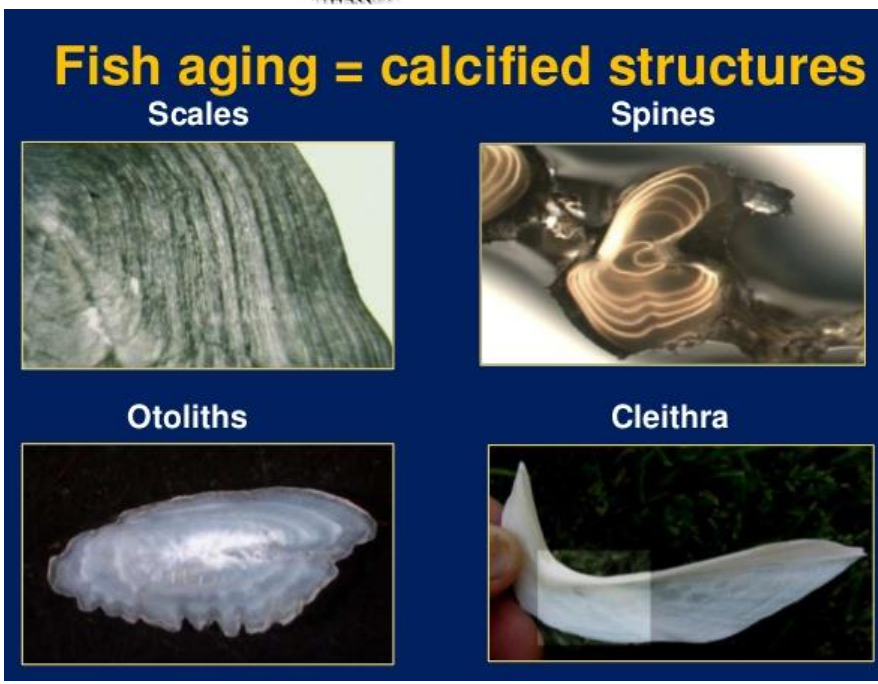
- The rate of growth in the diameter of these rings are proportional to the growth of the fish.

- *Scales* are easy to get, but may be unreliable if it has fallen off & new ones grown in their place…

- *Fin spines* may be unreliable for the same reason, & most fish don't have them with sufficient thickness for clear rings to be visible.

Unit 3: Pop. Dyn.: other concepts & terms





Unit 3: Pop. Dyn.: other concepts & terms

- *Otoliths* stay with the fish throughout life, but obtaining them requires killing the fish & require more preparation before ageing can be done.
- The *cleithrum* is a membrane bone that extends upwards from the base of the pectoral fin & anchors to the cranium above the gills….
- Has the same demerits as the otoliths.

Unit 3: Pop. Dyn.: other concepts & terms

- *Age group* (cohort) is a group of fish at given age.

- It is the actual age in years for fish of the same age, regardless of the year in which they were born.

- E.g.,
  - A fish in its 1st growing season belongs to *age-group 0*
  - A fish in its 2nd growing season belongs to *age-group 1* or simply age 1, etc.

Unit 3: Pop. Dyn.: other concepts & terms

- *Year class* is a group of fish spawned during a year in a stock, e.g. the 1987 year class would refer to fish that are age 0 in 1987, age 1 in 1988, etc.

- Hence, 2 fishes belonging to the same age group also belong to the same year-class.

- As they grow older, they'll belong to progressively older age groups, but remain in the same year-class.

Unit 3: Pop. Dyn.: other concepts & terms

- *Catch per unit effort* (CPUE) is the amount of fish catch taken per unit of fishing effort.

- It is the biomass (<u>number/weight</u>) of fish caught by an amount of effort exerted.

- <u>**NB:**</u> *f* is basically a combination of <u>gear type</u>, <u>gear size</u>, & <u>length of time a gear is used</u>.

Unit 3: Pop. Dyn.: other concepts & terms

- *CPUE* is influenced by changes in abundance.

- The basic assumption is that catch (***C***) & stock abundance/standing biomass (***B***) are related by:

$$C = q \cdot f \cdot \overline{B}$$

here ***q*** is the catchability coefficient

Unit 3: Pop. Dyn.: other concepts & terms

- Hence,

$$CPUE = \frac{C}{f} = q \cdot \overline{B}$$

- For practical purposes, *f* is standardised & fishing gears are kept constant to keep a simple relationship between ***CPUE*** & ***B***.

- This is to minimise the inherent measurement errors &/or variations in *f* & ***q***.

Unit 3: Pop. Dyn.: other concepts & terms

- *Catchability* is the average proportion of a stock that is taken by each unit of fishing effort.

- It is expressed mathematically as:

$$q = (C/f)*B$$

$$q = \text{CPUE}*B$$

- It is also called *gear efficiency* or *fishing power.*

Unit 3: Pop. Dyn.: other concepts & terms

- *Catchability* is strongly related to gear *selectivity* since it is <u>species</u> & <u>size</u> dependent.

- Sometimes, gear selection is simply defined as the relative change in ***q***.

- ***q*** ranges from 0 to 1, where **0 = no catch**; **1 =** entire stock; typically it's very small e.g. **0.000001**.

Unit 3: Pop. Dyn.: other concepts & terms

- But, the probability of a fish being caught at any time depends on several factors, not only *man-made*, & can broadly be grouped into
  - *biological* & *technological*

- *Biological factors* include:
  - fish availability on the fishing ground
  - fish behaviour towards the fishing gear
  - size, shape, & external features with some of these factors dependent on season, age, env't & other spp.

Unit 3: Pop. Dyn.: other concepts & terms

- Technological factors - a # of technological innovations have enabled fishers to greatly increase fish catch e.g.
  - new engines to power larger fishing vessels
  - refrigeration
  - factory trawlers
  - fish-locating equipment,
  - GPS technology,
  - gear type, design, size, colour, & material
  - gear position, duration, & handling

Unit 3: Pop. Dyn.: other concepts & terms

- Size *selectivity* is a generally important technical measure for fishing gears.

- It is the <u>probability of fish being retained in a fishing gear as a function of the length of the fish</u>.

- Several important selectivity measures are used:

Unit 3: Pop. Dyn.: other concepts & terms

- E.g. $\mathbf{L_{50}}$ = fish length, with fish having a probability of 50% being retained by the gear on encounter,
- Selection factor is L_{50} divided by mesh size in cm.
- Selection range is $\mathbf{L_{75} - L_{25}}$ (L_{75} & L_{25} are fish length where 75 % & 25 % of fish are retained respectively)

- So, all fishing gears are only able to catch a portion of the total (multi-species) fish community present.

Unit 3: Pop. Dyn.: other concepts & terms

- The use of the CPUE as an index of fish abundance is hence complicated by selectivity of a fishing gear.
- CPUE only reflect abundance of *fishable stock* or that part of a fish community caught by a specific gear.
- The <u>area of gear operation</u>, <u>size of the fish</u>, & the <u>fish inconstant behaviour relative to gear</u>, determine part of a stock that can be caught by a gear.

Unit 3, 2: Fisheries Management Theories

Unit 3: Pop. Dyn.: Fisheries mgt theories

- These are the fundamental basis upon which *managers* & *policy makers* try to <u>maximize yield</u> or other measures of output from a fishery.

- Traditional fishing studies are based on stable fishery populations.

- This had led to the dev't of *stock-recruitment theories* in fish population dynamics.

Unit 3: Pop. Dyn.: Fisheries mgt theories

- ‘*Stock*' refers to # of adult fish population, & '*recruitment*' is the # of juvenile fish entering the adult population.

- Stock-recruitment theories assume that abundance of *recruits* is influenced by abundance of *parents*.

- Hence, recruitment of new stock is a function of # *of eggs* produced & subsequent *survival of young*.

Unit 3: Pop. Dyn.: Fisheries mgt theories

- Since *total egg production* is based on *adult population size* & survival was deemed *constant*, it was believed that adult stock size could be controlled.

- This control, it was suggested, can be done through manipulating fishing pressure by regulating the;
  - **# of boats**,
  - **size of nets**, &
  - **total allowable catch**

Unit 3: Pop. Dyn.: Fisheries mgt theories

- This premise & later variations, became the basis for the mgt of fisheries for a long period.

- These theories suggest that fish *reproduction*, *survival*, & *productivity* are largely <u>independent of changes in physical env't of fish</u>.

- But fish population size is affected by other factors not just the spawning biomass or adult stock.

3: Fish. Theor.; (a) Max. Sustainable. Yield

- In *population ecology*, *Maximum Sustainable Yield* (MSY) is theoretically, the largest catch that can be taken from a fishery stock over an indefinite period.

- In *fisheries* terms, it is the largest average catch that can be taken from a stock over time under existing env'tal conditions without negatively impacting the reproductive capacity of the stock.

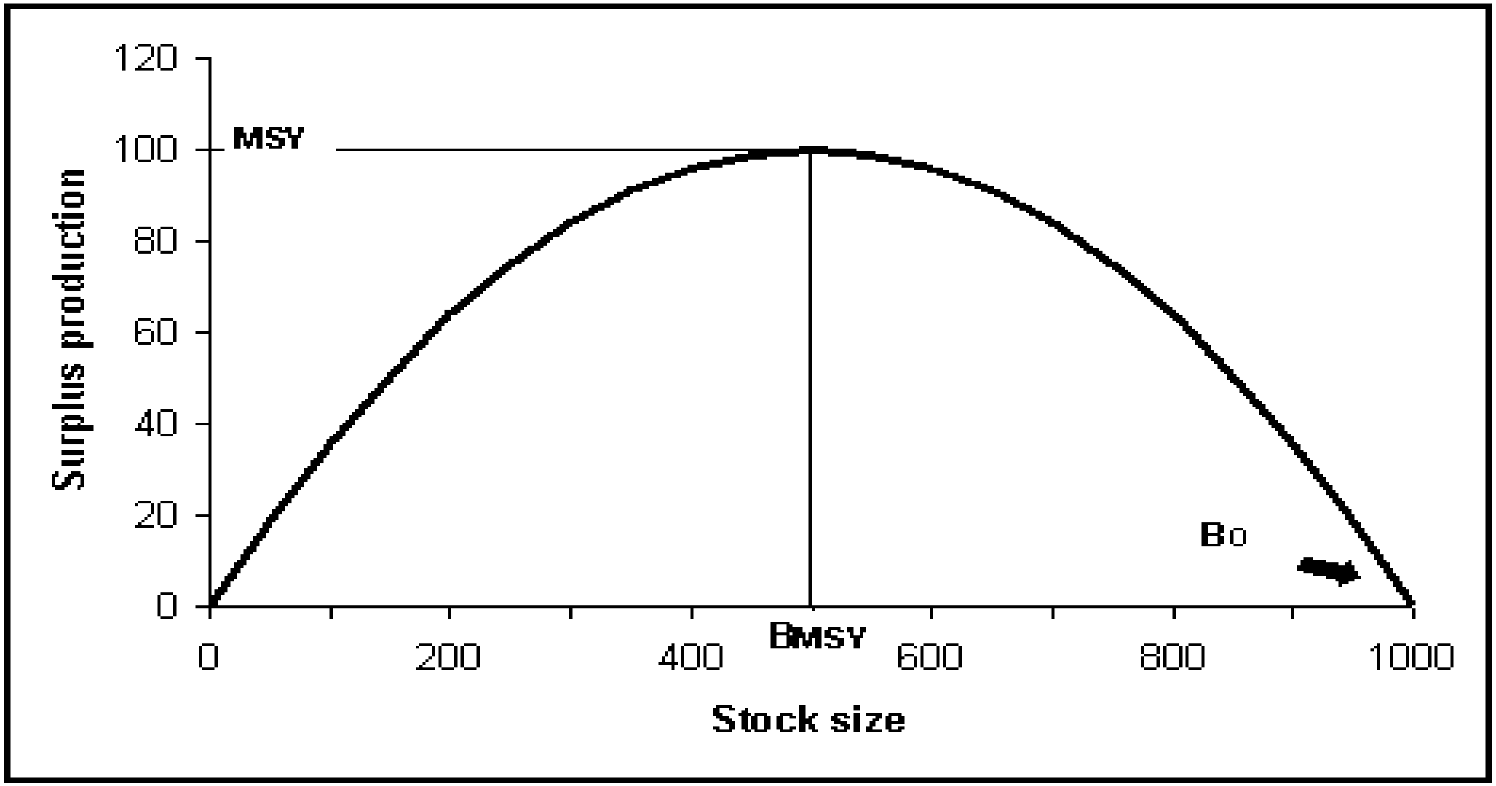
3: Fish. Theor.; (a) Max. Sustainable. Yield

- The *MSY* concept is based on a model, called *surplus production* or *biomass dynamic model*.

- It assumes that annual net growth in stock abundance increases as biomass of stock increases..

- This increase will continue until a certain biomass is reached at which this net growth, reaches a maximum (i.e. *MSY*)....

3: Fish. Theor.; (a) Max. Sustainable. Yield



3: Fish. Theor.; (a) Max. Sustainable. Yield

- This biomass is called B_{MSY} & the fishing mortality rate which will achieve MSY is called $F_{MSY.}$

- If biomass goes *above* $\mathrm{B_{MSY}}$, density-dependent factors e.g. competition (food, space), cannibalism, predation, etc start to reduce net population growth

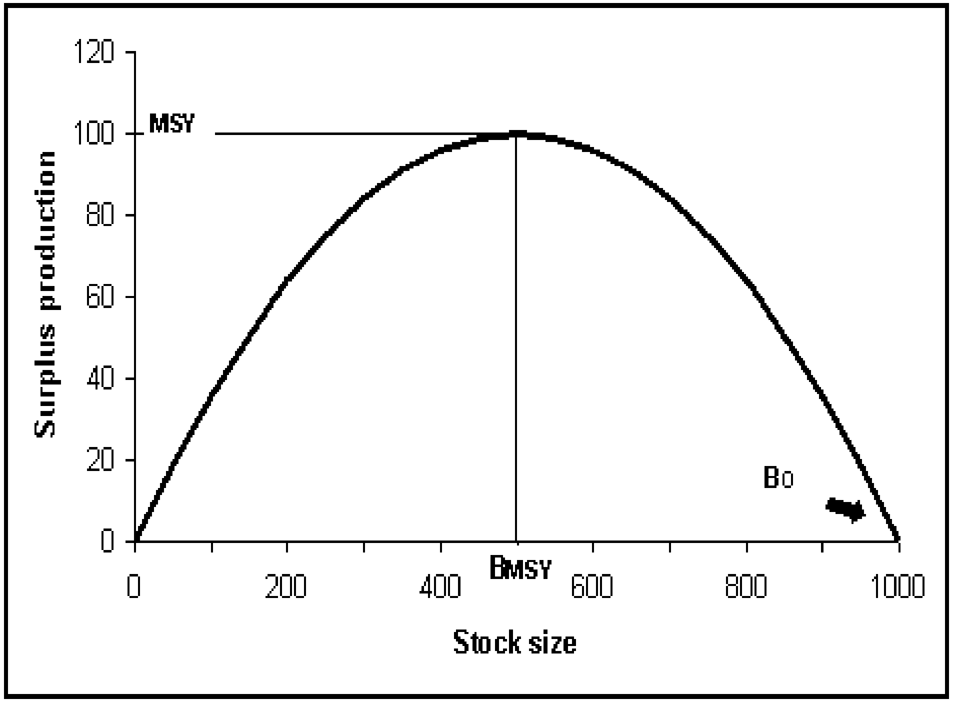
- The net N then decreases till at some point, *K*, where net population growth rate reaches zero (*B*o).

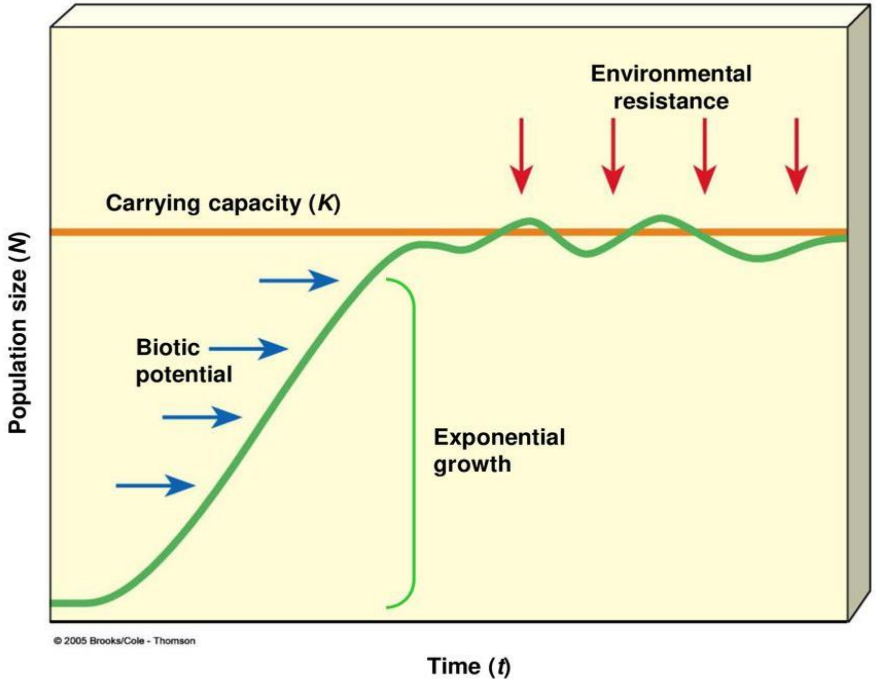
3: Fish. Theor.; (a) Max. Sustainable. Yield

- In reality, an unexploited stock will tend to vary around *Bo* because of env'tal changes….

- Basically, the MSY postulates that:
  - At low **N**, rate of population growth will increase since the env'tal resistance factors are low;..
  - Hence, at low *N*, rate of population growth increase till env'tal resistance factors begin to limit N & this point is called *MSY*…

3: Fish. Theor.; (a) Max. Sustainable. Yield





3: Fish. Theor.; (a) Max. Sustainable. Yield

- As *N* becomes larger than the MSY, the rate of population growth decreases & the number of individuals that can be fished does not increase.

- <u>MSY</u> is the point where highest rate of <u>recruitment</u> can occur & the highest rate of <u>harvesting</u> can occur at the point where the highest recruitment occurs.

3: Fish. Theor.; (a) Max. Sustainable. Yield

- MSY aims at a *balance between too much & too little harvest* to keep the population at some intermediate abundance with a maximum replacement rate.

- It seeks to decrease population density to the point of highest growth rate possible.

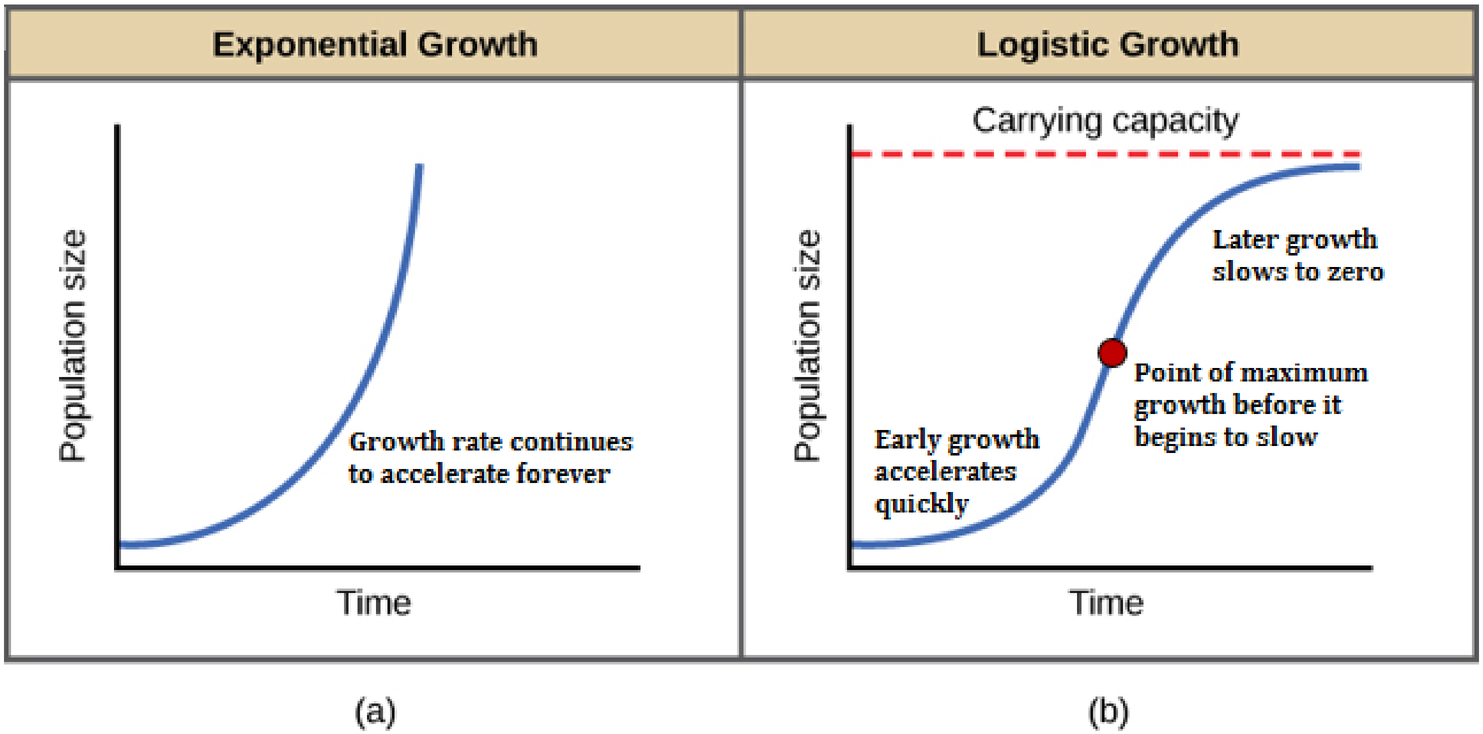
- This changes ***N***, but the new number can be maintained indefinitely under ideal conditions.

3: Fish. Theor.; (a) Max. Sustainable. Yield

- MSY is based on the *logistic growth model* in which a population introduced to a new habitat (with plenty of resources & less competition) or with low #s goes through a lag phase of slow growth at first…

- Once it reaches a stable population it goes through rapid growth rate (log phase) that starts to level off (stationary phase) once the species reaches *K*. …

3: Fish. Theor.; (a) Max. Sustainable. Yield

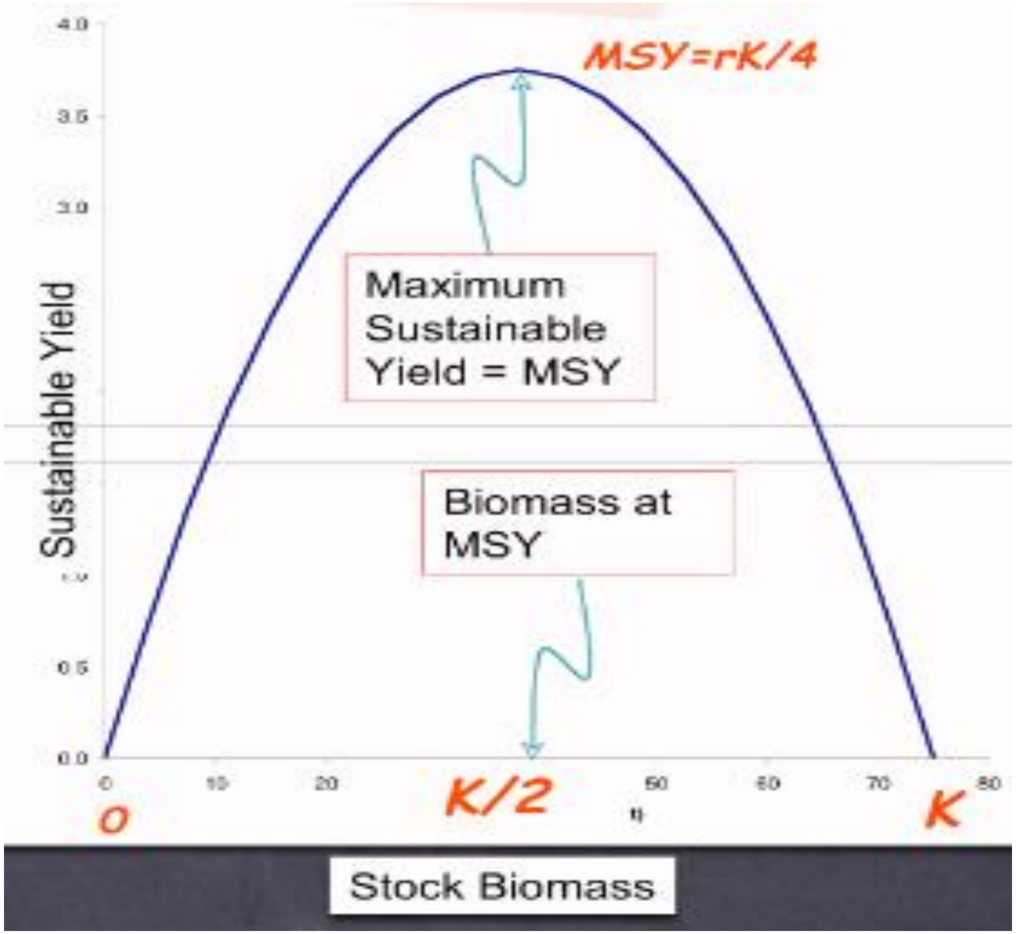


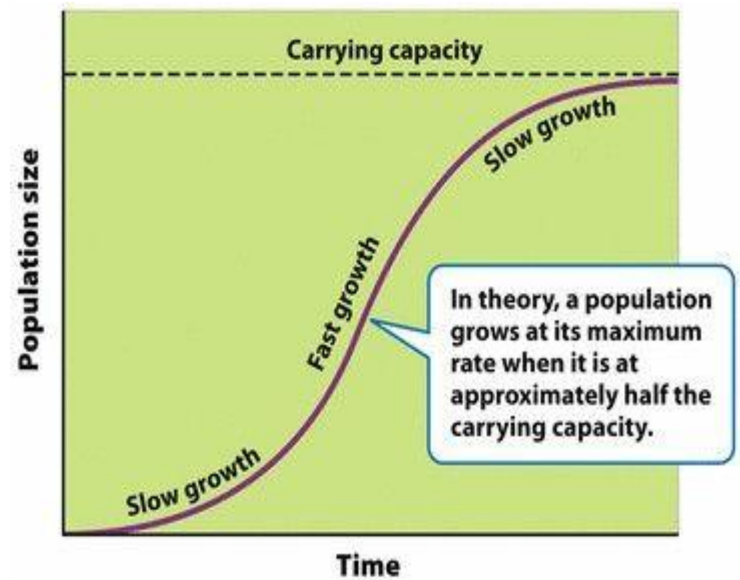
3: Fish. Theor.; (a) Max. Sustainable. Yield

- Under the assumption of *logistic* growth, the <u>*MSY* will be exactly at ½ the *K* of a species, as this is the stage at which population growth is highest</u>….

- But, *MSY* estimates are typically based on <u>limited data</u> with considerable <u>uncertainties</u> e.g.
  - *scientific* uncertainty about stock dynamics;
  - *measurement error* in stock dynamics; &
  - *env'tal variability* affecting stock productivity

3: Fish. Theor.; (a) Max. Sustainable. Yield





3: Fish. Theor.; (a) Max. Sustainable. Yield

- Hence, overestimates are common & this results in unsustainable harvesting making subsequent recovery difficult.

- To reduce the risk of overestimation, an *optimum sustainable yield* (OSY) usually set at 10 – 20% below the MSY is proposed .

3: Fish. Theor.; (a) Max. Sustainable. Yield

- OSY is seen as the harvest level for a particular fish sp. that achieves the greatest overall benefits taking into account *economic*, *social*, & *biological* factors.

- MSY considers only the *biology* of the species.

3: Fish. Theor.; (a) Max. Sustainable. Yield

- MSY is widely used for fisheries mgt, but several *shortcomings* have been identified.

- For e.g., the key assumptions the MSY are;
  - *non-fishing mortality* is constant & *fishing mortality* is the only driving variable;
  - that *population abundance* can be controlled by simply *increasing* or *decreasing* fishing pressure

3: Fish. Theor.; (a) Max. Sustainable. Yield

- Thus, it focuses on the *biology* of target organism.

- So, it is criticized as ignoring other *key factors* in mgt of fisheries which has led to the collapse of many fisheries by focusing solely on the sp. in question.

- It also treats all individuals of a target population as identical & hence ignores all aspects of population structure (e.g. *size*, *age*, *survival*, *reproduction*, *growth rates*, etc) & *damage* to the ecosystem, etc.

3: Fish. Theor.; (a) Max. Sustainable. Yield

- These puts the fishery at much *risk*.

- Other reasons that affect MSY sustainability are, it;
  - considers only the benefits, not the costs of harvest
  - is too sensitive to *political pressure*
  - ignore the issue of *bycatch*

- *Bycatch* refers to fish & other aquatic organisms taken in addition to the target fish unintentionally.

3: Fish. Theor.; (a) Max. Sustainable. Yield

- Bycatch are unwanted aquatic spp. caught incidentally & constitutes a major threat to marine endangered species.

- It is discarded after catching either dead or almost dead because they are either <u>undersized</u> or <u>unwanted species</u>, & usually <u>cannot be sold</u>.

3: Fish. Theor.; (a) Max. Sustainable. Yield

Bycatch

3: Fish. Theor.; (a) Max. Sustainable. Yield

- Since MSY ignores many key aspects of a fishery, *conservation biologists* regard it widely as dangerous, misused, & not always easy to apply in practice.

- Biologists, for e.g., don't always have enough data to make a clear determination of ***N*** & <u>growth rate.</u>

- So, as a mgt goal, the static interpretation of MSY (i.e. <u>fixed catch</u> that can be taken yearly) is wrong.

3: Fish. Theor.; (a) Max. Sustainable. Yield

- E.g., it ignores the fact that ***N*** undergo <u>natural changes</u> in abundance & will usually become severely depleted under a *constant-catch strategy*.

- The *traditional goal* in fisheries mgt has been to obtain *continuing yields* from a living 'resource.'

- So, concerns are raised when populations fall below levels that provide adequate yields or which fail to meet other specified concerns.

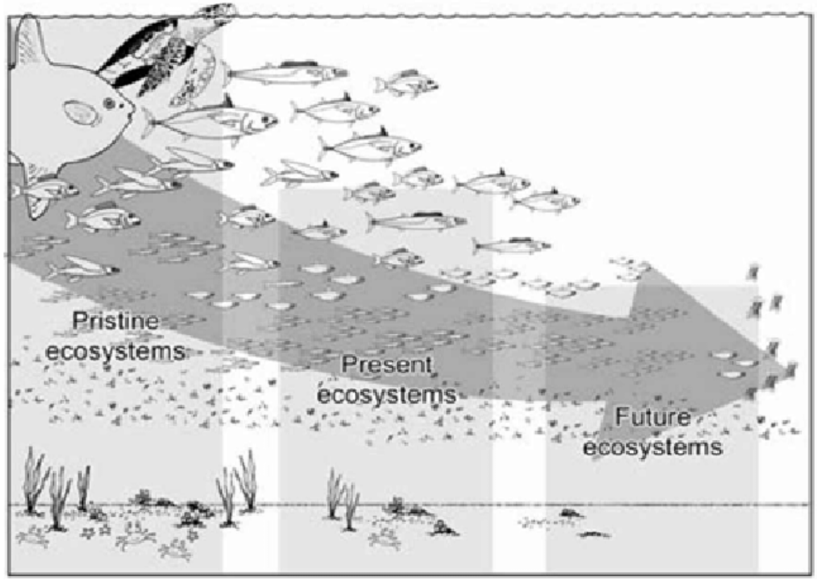
3: Fish. Theor.; (a) Max. Sustainable. Yield

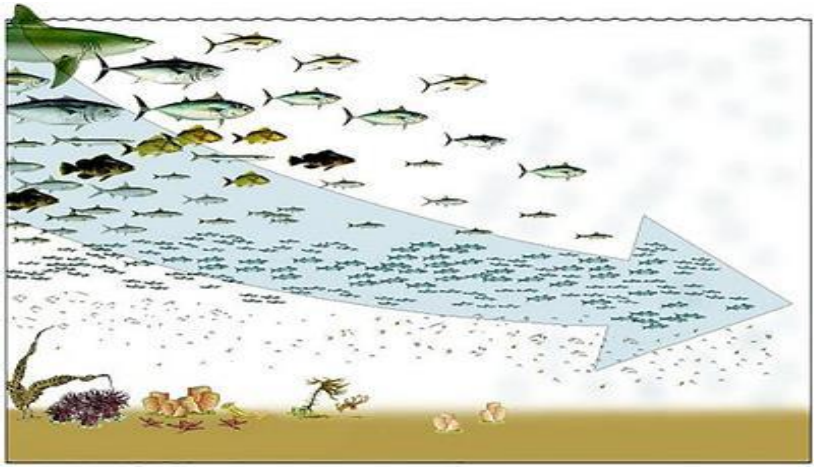
- *Top predatory fishes* with relatively low reproductive capacities are often overexploited e.g. sharks, etc.

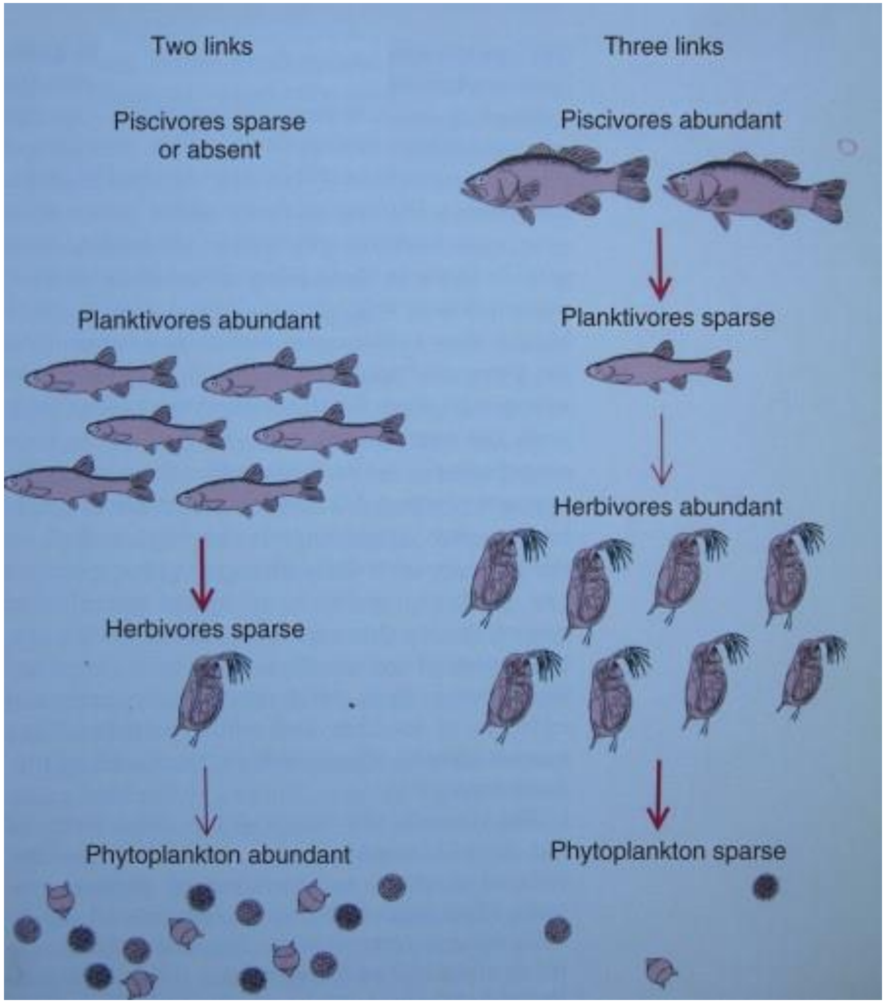
- As increasing fishing pressure cause their #s to fall, organisms at progressively lower trophic levels begin to dominate foodwebs of aquatic ecosystems.

- Fishers in turn target fish populations at these lower trophic levels, a phenomenon described as "fishing down the foodwebs…"

3: Fish. Theor.; (a) Max. Sustainable. Yield







Fishing down aquatic foodwebs

3: Fish. Theor.; (a) Max. Sustainable. Yield

- To prevent stock overfishing, managers typically set *quotas* aimed at adhering to MSY of the fish stock i.e. limits are set on catches (*total allowable catch*).

- This is done so that stocks are maintained at a level that will preserve the long-term viability of the target species or K.

- Quotas for targeted spp. usually take into account;

3: Fish. Theor.; (a) Max. Sustainable. Yield

- the lifespan of the target fish;
- its population growth rate;
- allowable catch size; &
- its reproductive capacity

- These are all *biological attributes* & so the MSY emphasizes only the biology of the targeted commercial or recreational fishery & is not *holistic*.

3: Fish. Theor.; (b) Ecol. Sustainable. Yield

- In this model, a fishery is sustainable if;
  - it can be fished indefinitely at reasonable levels
  - while maintaining the *ecosystem* (structure, function, & diversity) on which the fishery depends, &
  - the integrity of the habitat essential to the fish species

3: Fish. Theor.; (b) Ecol. Sustainable. Yield

- Fisheries protection needs a good understanding of the *entire ecosystem* involving multiple species, not just the targeted *commercial* or *recreational* organism.

- This understanding is the basis for achieving an *ecologically sustainable yield* (ESY).

- *ESY* is the yield an aquatic ecosystem can sustain without undergoing an undesirable change in state.

3: Fish. Theor.; (b) Ecol. Sustainable. Yield

- Fisheries managers are reassessing the MSY approach to sustaining populations of exploited spp.

- This is because target fish species are part of the aquatic ecosystem in which they interact with other organisms (e.g. as food sources, competitors, etc).

- They also interact with their physical & chemical env't (e.g. suitable breeding, feeding habitats, etc).

3: Fish. Theor.; (b) Ecol. Sustainable. Yield

- E.g., a decline in population of a particular fish sp. targeted in MSY, may have a rippling or cascading effect on the entire ecosystem.

- This may result in changes in its *biotic composition* & a *reduction in its stability*.

- E.g. when fishermen decimate populations of *commercially attractive fish* e.g. cod, tuna, etc at top of some aquatic foodwebs.

3: Fish. Theor.; (b) Ecol. Sustainable. Yield

- Hence, *ESY* advocates for a more holistic approach to fisheries mgt.

- ESY's foundation is the *ecosystem-based management approach* (*EMA*).

- EMA is an env'tal mgt tool that recognizes full array of interactions in an ecosystem, including *humans*, rather than considering single issues, sp., or ecosystem services in isolation.

3: Fish. Theor.; (b) Ecol. Sustainable. Yield

- Many factors are considered in EMA & this *challenges* its implementation e.g.;
  - Improving/creating access for *public participation* in objective setting & in prioritizing those objectives;
  - developing *operational protocols* taking into account foodweb complexity,
  - *climate change*; &
  - determining *functional value of habitat-related ecosystem* goods (e.g. food, etc) & services (e.g. CO_2 absorption, etc) that benefit humanity

3: Fish. Theor.; (b) Ecol. Sustainable. Yield

- E.g. it requires *floor habitats protection* by phasing out destructive trawling practices & expanding protected areas such a *marine reserves* where fishing is prohibited.

- The establishment of protected areas or reserves are usually justified from 2 points of view:
  - *protection* of areas crucial to the maintenance & even population expansion (e.g. *provide reproductive reserves*) of fishery species; &

3: Fish. Theor.; (b) Ecol. Sustainable. Yield

- *protection* of very diverse structural habitats e.g. coral reefs or other communities that are deemed to be of importance for economic, educational, or aesthetic reasons

Unit 3: Pop. Dyn.: Threats: Overfishing

- Several different threats to fisheries are recognized world-wide & include but not limited to;
  - **Overfishing***
  - Introduction of **exotic species**
  - **Conversion of sites** for other purposes
  - **Deforestation**
  - **Pollution**
  - Bad **policies**
  - **Poor-land use planning**
  - **Climate change**
  - **Changes in water regimes** e.g. diversion & irrigation

Unit 3: Pop. Dyn.: Threats: Overfishing

- This is the removal of a species of fish from a water body at a rate greater than its replenishment rate, resulting in *under-population*.

- It can occur in water bodies of any sizes, e.g. ponds, rivers, lakes or oceans, etc.

- It often result in *stock depletion*, *reduced biological growth rates*, & *low biomass levels*.

Unit 3: Pop. Dyn.: Overfishing

- Sustained overfishing can lead to critical *depensation*, where fish population is no longer able to sustain itself.

- *Depensation* is the effect on a population where some factors (e.g. predation, etc) *cause a decrease in the breeding population* leading to reduced production & survival of eggs or offspring…

Unit 3: Pop. Dyn.: Overfishing

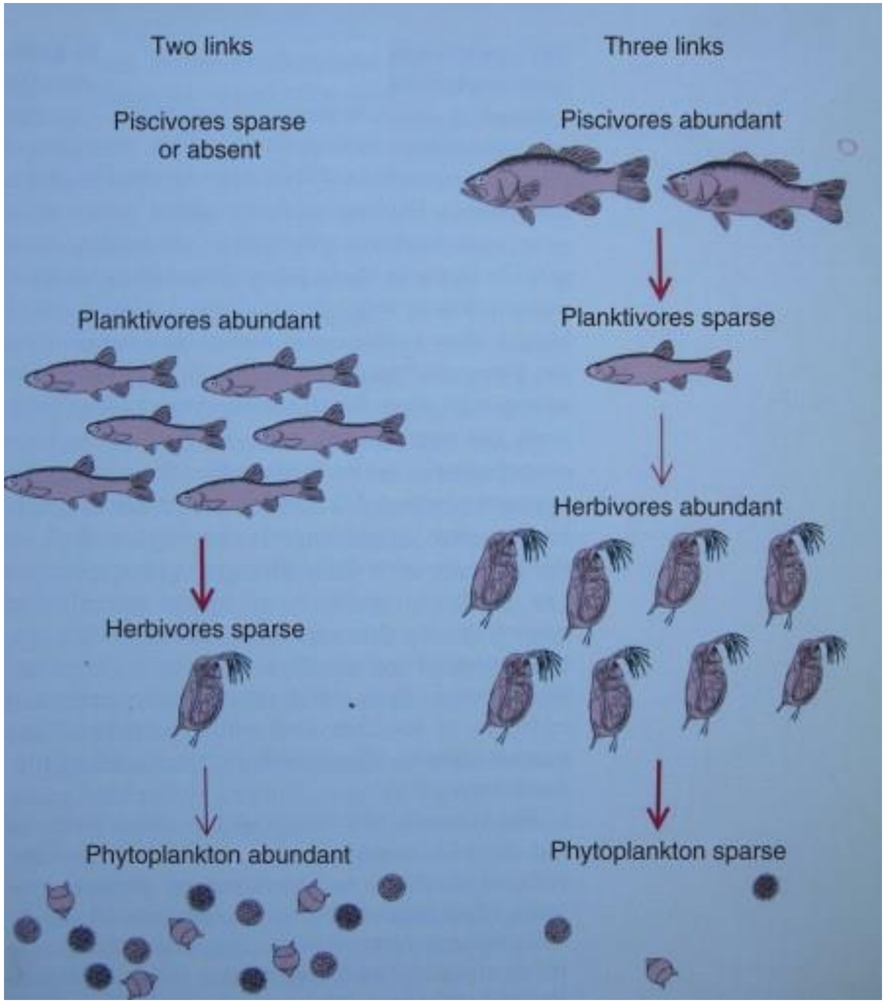
- Some forms of overfishing (e.g. sharks), has led to the collapse of entire marine ecosystems.
- Ability of a fishery to recover from overfishing depends on whether the ecosystem's conditions are suitable for recovery.
- This is because significant changes in fish species composition can result in an ecosystem shift.

Unit 3: Pop. Dyn.: Overfishing

- When this happens, a new balance is formed where energy flows involve spp compositions different from those that had been present before the depletion of the original fish stock…

- E.g. once trout have been overfished, carp might take over in a way that makes it impossible for the trout to re-establish a breeding population.

Unit 3: Pop. Dyn.: Overfishing



Ecosystem shift due to predation

Unit 3: Pop. Dyn.: Overfishing

- The notion of overfishing hinges on what is meant by an "*acceptable level*" of fishing:

- *Biological overfishing* occurs when fishing mortality reaches a level where stock biomass has reduced rate of growth i.e. fish are taken out of the water faster than they can replace themselves by breeding.

- If this continues long enough, **N** will decrease.

Unit 3: Pop. Dyn.: Overfishing

- *Bioeconomic overfishing* considers the cost of fishing when determining acceptable catches.

- Here, a fishery is overfished when catches exceed maximum economic yield (MEY) where resource rent is at its maximum.

- Fish are removed so quickly that the financial profitability of the fishery is sub-optimal.

Unit 3: Pop. Dyn.: Overfishing

- *Harvest control rule* (HCR) is a model for predicting <u>acceptable levels</u> of fishing.

- It is a set of *tools* & *protocols* managers use to directly <u>control harvest rates</u>, & *strategies* for <u>predicting stock status</u>, & <u>long-term sustainability</u>.

Unit 3: Pop. Dyn.: Types of Biological Overfishing

- There are 3 recognized types of *biological overfishing*:
  - **growth** overfishing,
  - **recruit** overfishing**, &**
  - **ecosystem** overfishing

Unit 3: Pop. Dyn.: Types of Biological Overfishing

- a) *Growth overfishing* - occurs when fish are harvested at an average size smaller than the size that would produce the maximum yield per recruit.

- It is the excessive removal of smaller-sized fish that hinders the ability of the fishery to produce its maximum yield.

Unit 3: Pop. Dyn.: Types of Biological Overfishing

a) *Growth overfishing* (cont)-

- Growth overfishing does not affect the ability of a fish population to replace itself.

- This makes total yield less than it would be if the fish were allowed to grow to an appropriate size.

- It is countered by reducing fishing mortality & increasing average size of harvested fish.

Unit 3: Pop. Dyn.: Types of Biological Overfishing

- b) *Recruitment overfishing* is when mature adult population (spawning biomass) is depleted to a level where it no longer has the reproductive capacity to replenish itself.

- There are not enough adults to produce offspring due to high fishing mortality such that production of new recruits to the fishery is adversely affected.

Unit 3: Pop. Dyn.: Types of Biological Overfishing

b) *Recruitment overfishing* (cont)

- The # of fish removed is greater than the # gained from fish remaining & reproducing.

- It is countered by increasing spawning biomass to a target level to restore an overfished population to sustainable levels.

- This is done by placing *moratoriums*, *quotas*, & *minimum size limits* on a fish population.

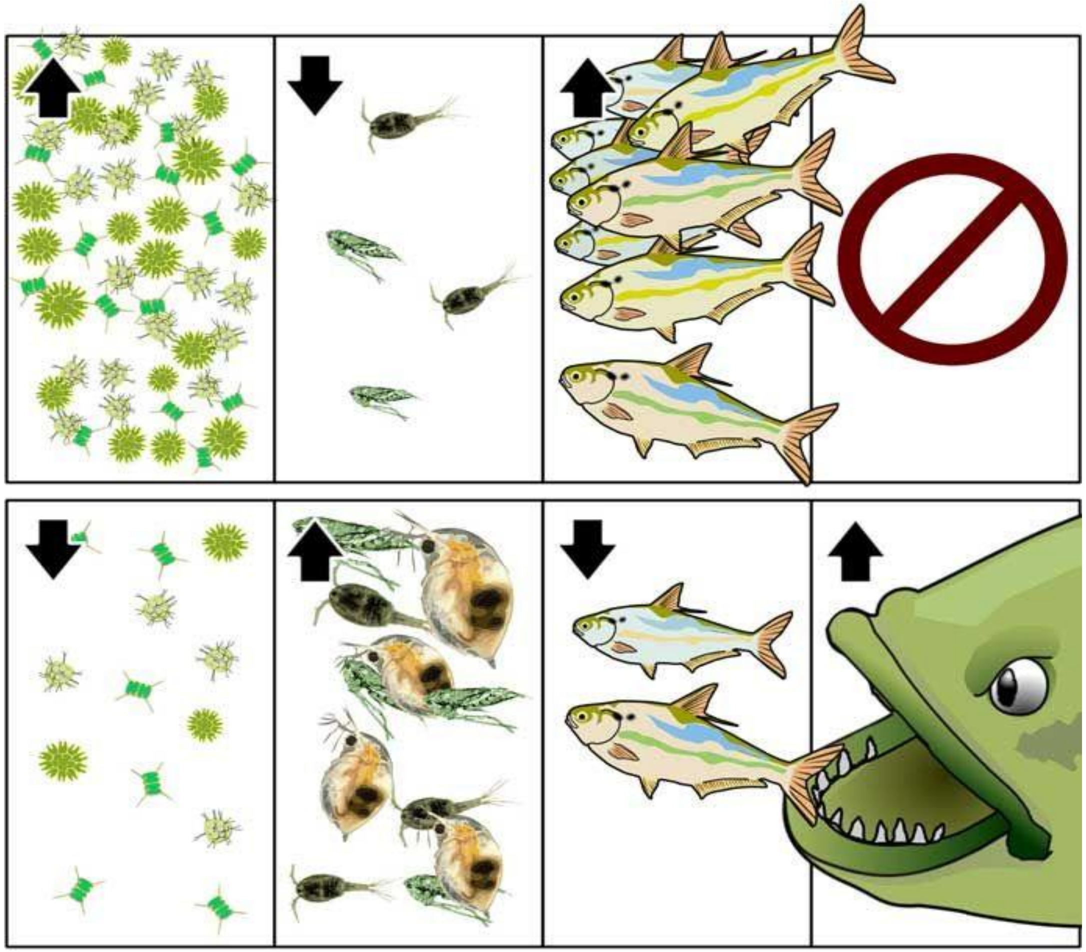
Unit 3: Pop. Dyn.: Types of Biological Overfishing

- c) *Ecosystem overfishing* occurs when the balance of the ecosystem is altered by overfishing.

- With *declines* in abundance of large predatory species, abundance of small forage type increases causing a shift in the balance of the ecosystem towards smaller fish species…

- It is based on *trophic cascade concept*.

Unit 3: Pop. Dyn.: Types of Biological Overfishing



Trophic cascade in aquatic foodwebs

Unit 3: Pop. Dyn.: Types of Biological Overfishing

c) *Ecosystem overfishing* (cont)

- It occurs when *predators* in a food chain suppress the abundance of their *prey*, thereby releasing the next lower trophic level from predation or herbivory.

- E.g., if the abundance of large *piscivore* is increased in a lake; abundance of their prey, zooplanktivores, should decrease, large zooplankton abundance should increase, & phytoplankton biomass should decrease…

Unit 3: Pop. Dyn.: Types of Biological Overfishing

c) *Ecosystem overfishing* (cont)

- It is important for understanding the effects top predator removals from food webs, as humans have done in many places through overfishing.

- Removal of piscivorous fish can change lake water from clear to green by allowing phytoplankton to flourish.

What renders species susceptible to overfishing?

- …about 5 *key features* of the biology of fishes & the motivations of fishermen…

- Fish stocks that are most vulnerable to overfishing typically have the following features;
  - Catchability remains high as N decreases
  - Are highly valuable
  - Are susceptible to capture as non-target species
  - Life histories result in low productivity
  - Per capita recruitment decreases as N decreases

What's needed to safeguard fish diversity mitigate overfishing?

- UN *Law of the Sea*
  - **61** & **62 -** coastal nations to ensure maintenance of living resources in their EEZs, prevent overexploitation, & restore depleted stocks
  - **65** – prohibit, limit, regulate exploitation of organisms

- G*overnment regulations*
  - These measures include fishing quotas, bag limits, licensing, closed seasons, size limits & the creation of marine reserves & other marine protected areas.

What's needed to safeguard fish diversity mitigate overfishing?

- Adoption of the *precautionary principle*
- Individual *Transferable Quotas (ITQs)*
- *Targeted management at key points in the life history*
- Removal of *subsidies*
- *Fishing techniques* could be altered to minimize fishing impact
- Use of *aquaculture*
- Consumer *awareness*