Lecture 12

Common-Pool Resources: Fisheries and Other Commercially Valuable Species

Common-Pool Resources: Fisheries and Other Commercially Valuable Species

- Introduction
- Efficient Allocations
- Appropriability and Market Solutions
- Public Policy toward Fisheries

Introduction

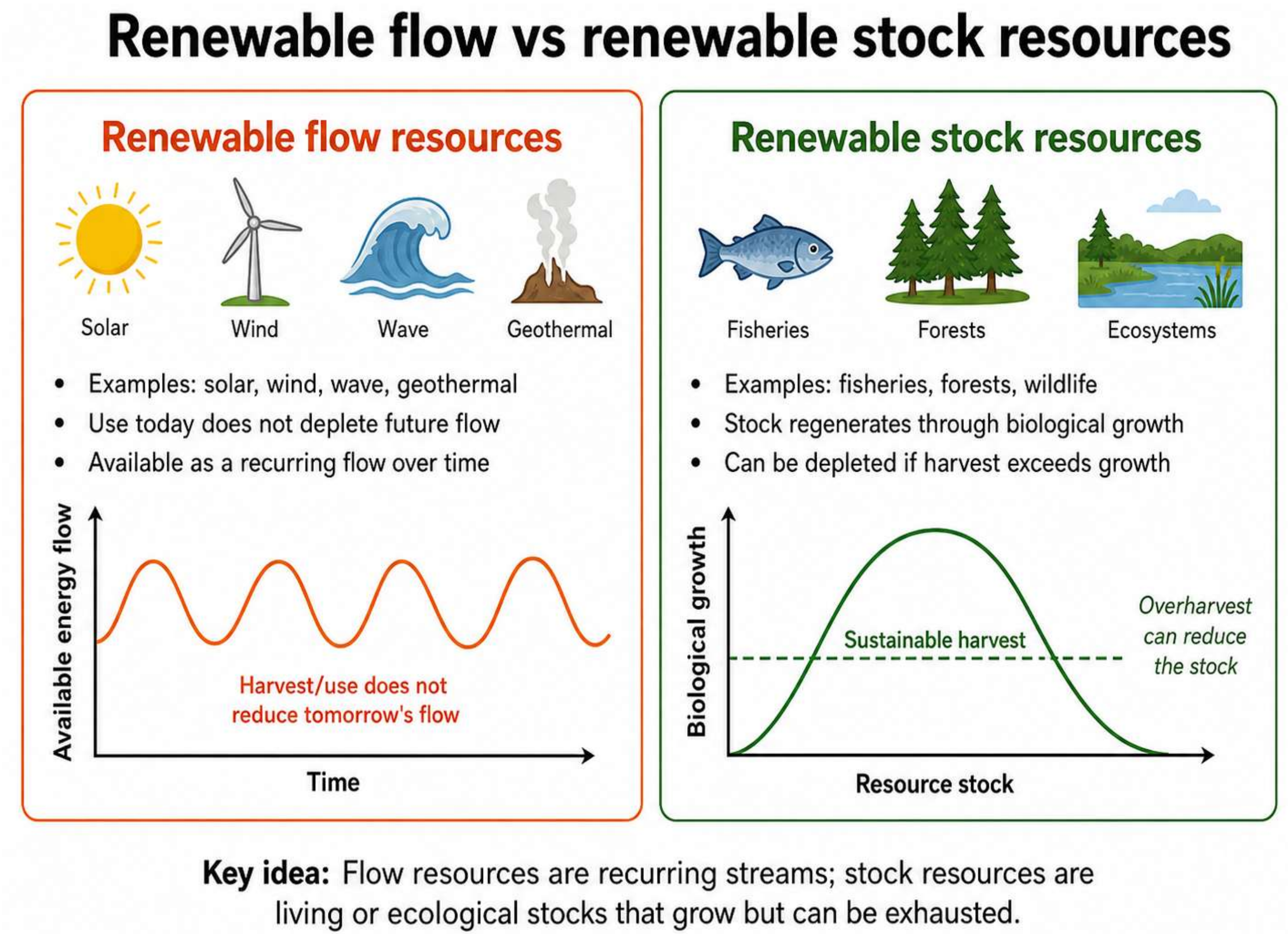
- Distinguish between

1. Renewable flow resources: such as solar, wave, wind and geothermal energy) which are non-depletable.

2. Renewable stock resources: such as, **(i)** living organisms: fish, cattle and forests, with a natural capacity for growth; **(ii)** inanimate systems (such as water and atmospheric systems): reproduced through time by physical or chemical processes; **(iii)** arable and grazing lands as renewable resources: reproduction by biological processes (such as the recycling of organic nutrients) and physical processes (irrigation, exposure to wind etc.) which are **capable** of being fully exhausted.

- This chapter examines renewable resources with biological growth.
- This chapter focuses on common pool resources (fisheries).
- An economic model is integrated with a biological model.
- Efficient levels of harvest are defined and economic incentives for sustainable harvests are discussed.

Introduction



Biological growth processes

Biological Dimension—The Schaefer model

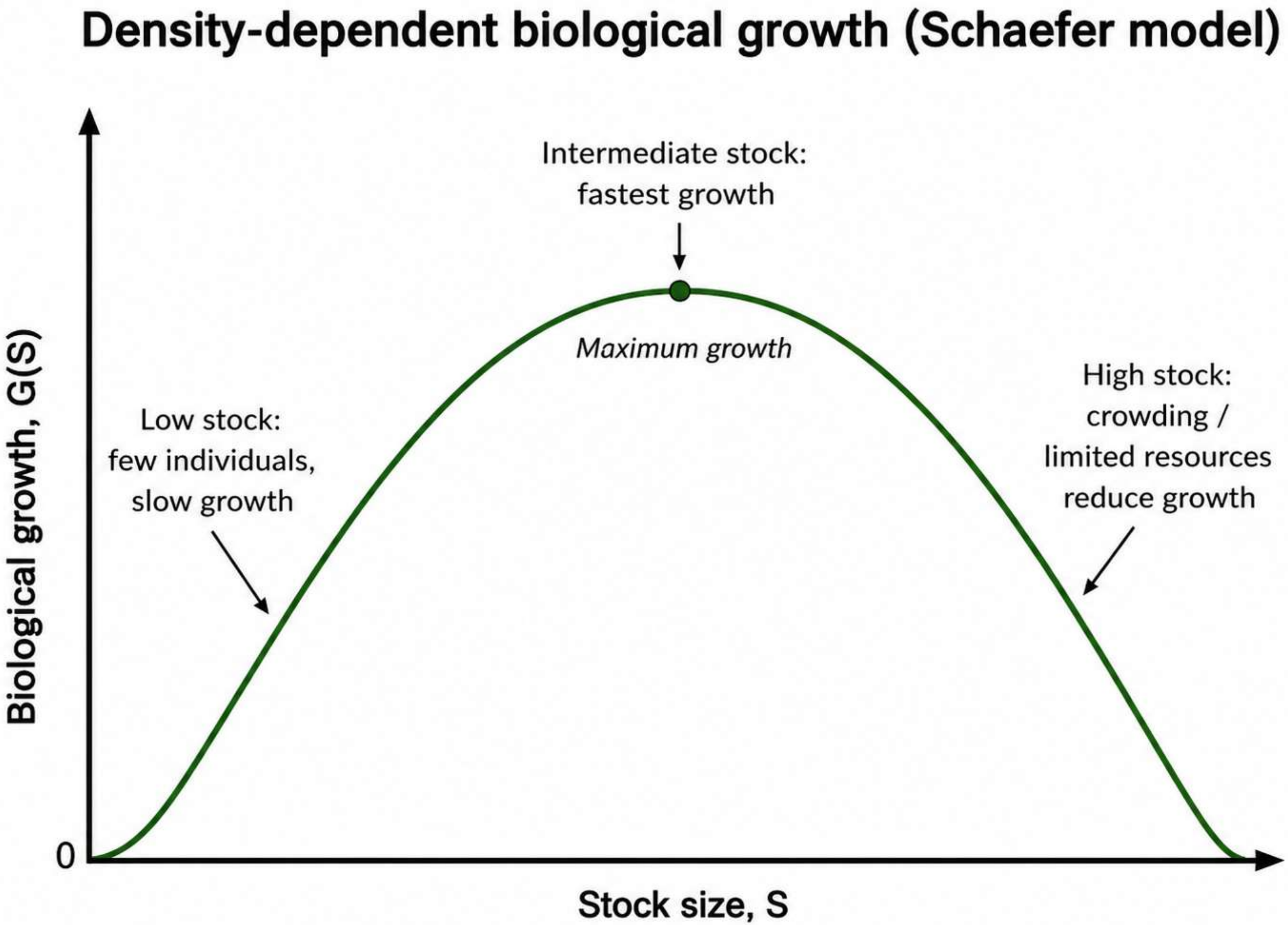
- The Schaefer model describes how a biological stock, such as a fish population, grows over time.
- Growth depends on the current stock size.

$$G_t = S_{t+1} - S_t$$

–where S is the stock size and G is the growth between t and t+1

- **Main idea:** Population growth is density dependent. That means growth changes as the population becomes more crowded.
- **Intuition:** When the stock is very small, there are too few individuals to reproduce quickly, so growth is low. When the stock is intermediate, reproduction is strong and crowding is limited, so growth is high. When the stock is very large, crowding, food limits, disease, or competition reduce growth.
- In continuous time notation: $G = G(S)$
- **Key takeaway:** Biological growth is not constant. It first rises with stock size, reaches a maximum, and then falls as crowding becomes important.

Biological growth processes



Biological growth processes

Biological growth processes

The Schaefer model

- Growth depends on stock size:

$$G = G(S)$$

- Discrete time:

$$G_t = S_{t+1} - S_t$$

- Simple logistic growth:

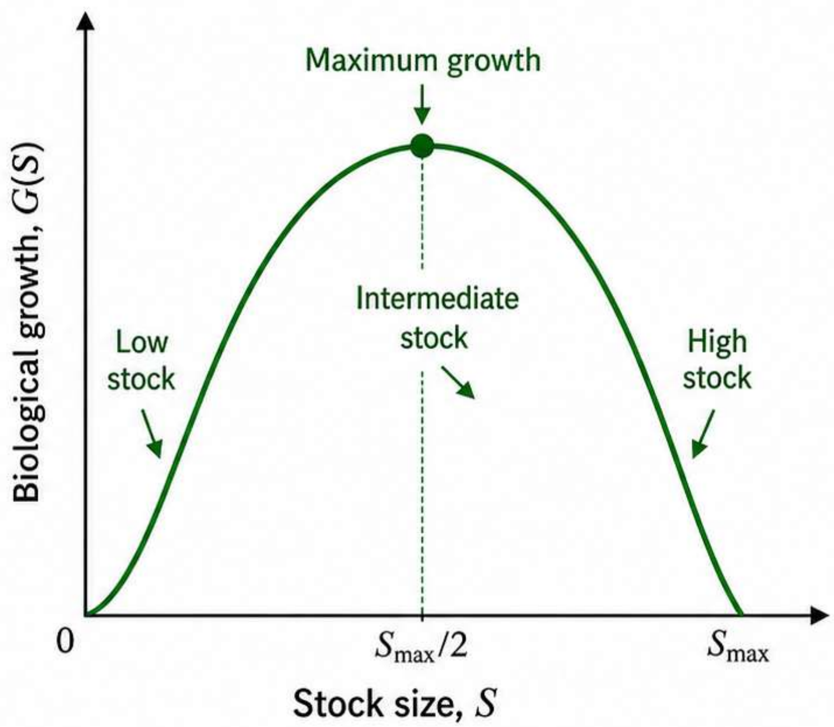
$$G(S) = gS\left(1 - \frac{S}{S_{\max}}\right)$$

- This is **density-dependent** growth.

Intuition

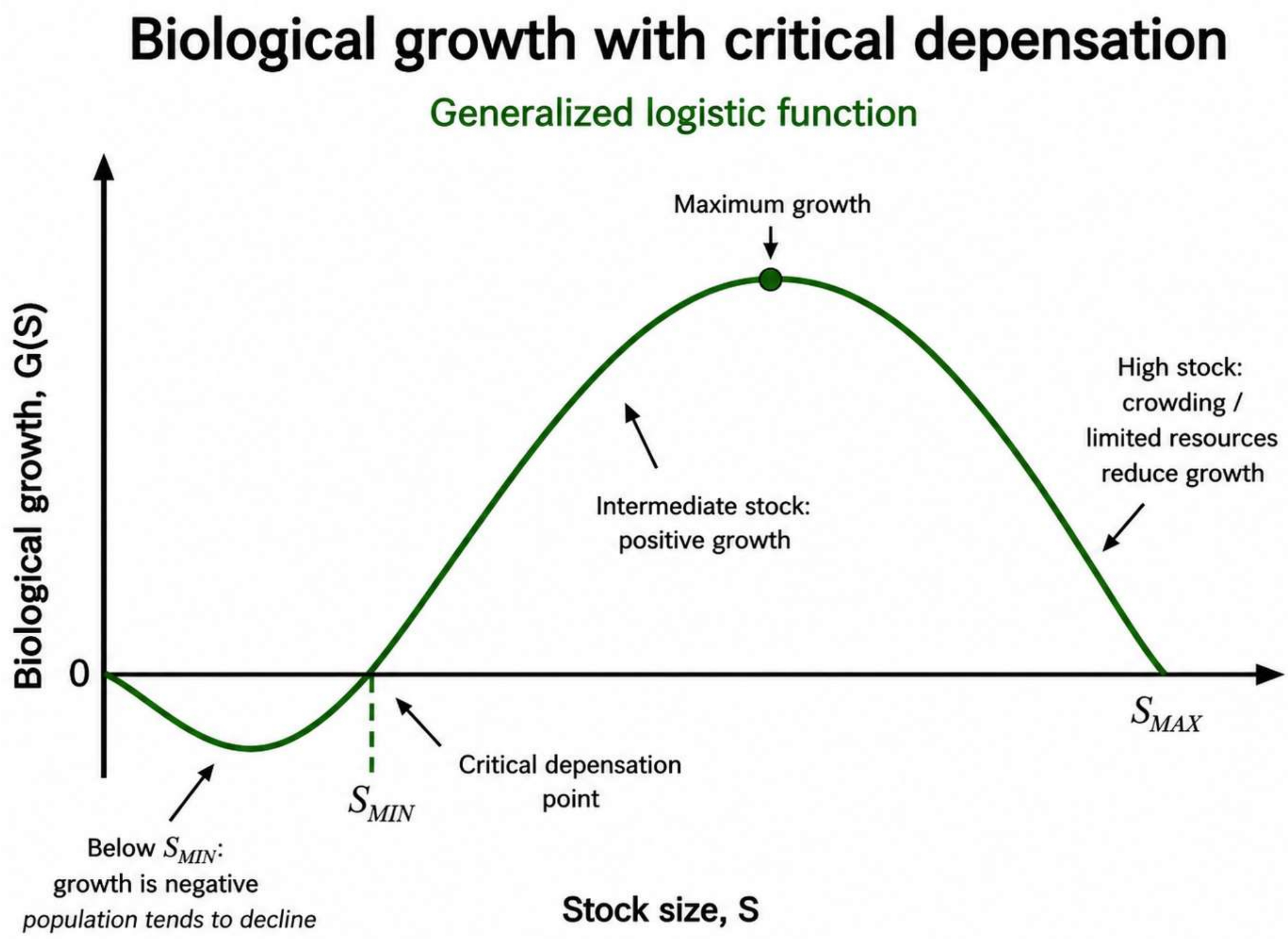
- Low stock: few individuals → low growth
- Intermediate stock: fastest growth
- High stock: crowding / limited resources → low growth

Logistic growth curve



Key idea: growth rises with stock size at first, peaks at an intermediate stock, and then falls as crowding increases.

Biological growth processes



Biological growth processes

- There are many forms the G = G(S) function can take

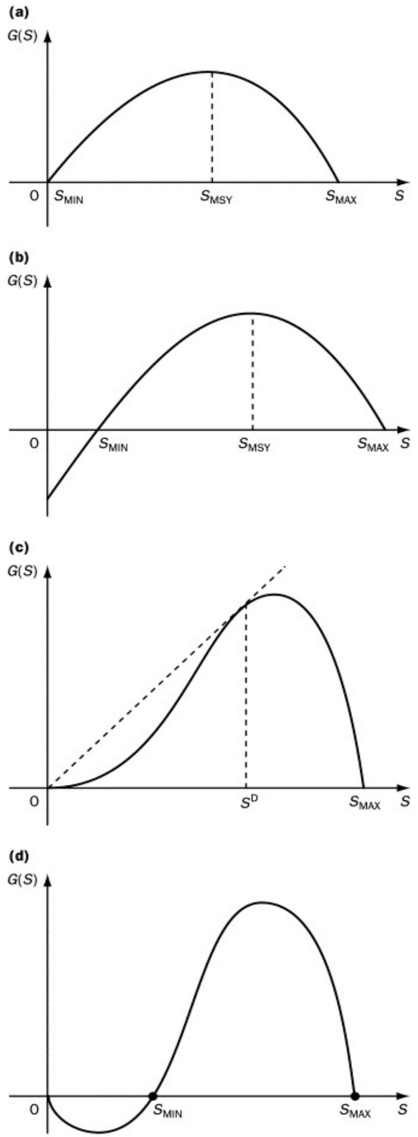
- An example: (simple) logistic growth –

$$G(S) = gS\left(1 - \frac{S}{S_{MAX}}\right)$$

Where g is the intrinsic growth rate (birth rate minus mortality rate) of the population.

Suppose that in the initial period of time ($t = 0$) the stock, S, is zero. Then something happens so that in $t = 1$, the stock rises to *0.01*.

$$S_{t+1} = gS_t\left(1 - \frac{S_t}{S_{MAX}}\right) + S_t$$



Simple logistic growth Figure a

$$\dot{S} \equiv \frac{dS}{dt} = g\left(1 - \frac{S}{S_{MAX}}\right)S$$

or equivalently

$$G(S) = g\left(1 - \frac{S}{S_{MAX}}\right)S$$

Logistic growth with a positive population minimum threshold level, S_{MIN} Figure b

$$G(S) = g(S - S_{MIN})\left(1 - \frac{S}{S_{MAX}}\right)$$

Modified logistic model (with $\alpha > 1$) exhibiting depensation Figure c

$$G(S) = gS^{\alpha}\left(1 - \frac{S}{S_{MAX}}\right)$$

Generalised logistic function *with critical depensation*: Figure d

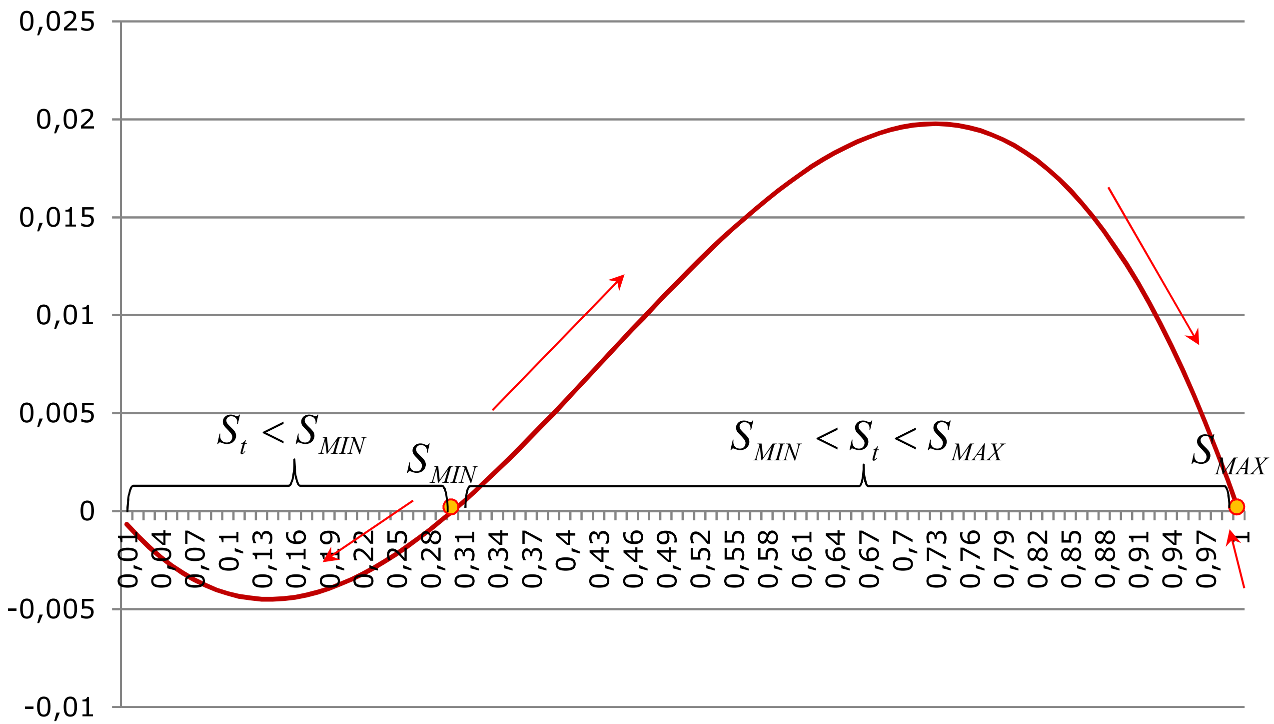
$$G(S) = g\left(\frac{S}{S_{MIN}} - 1\right)\left(1 - \frac{S}{S_{MAX}}\right)S$$

Fish Population and Growth

- An example of generalised logistic function with critical depensation*

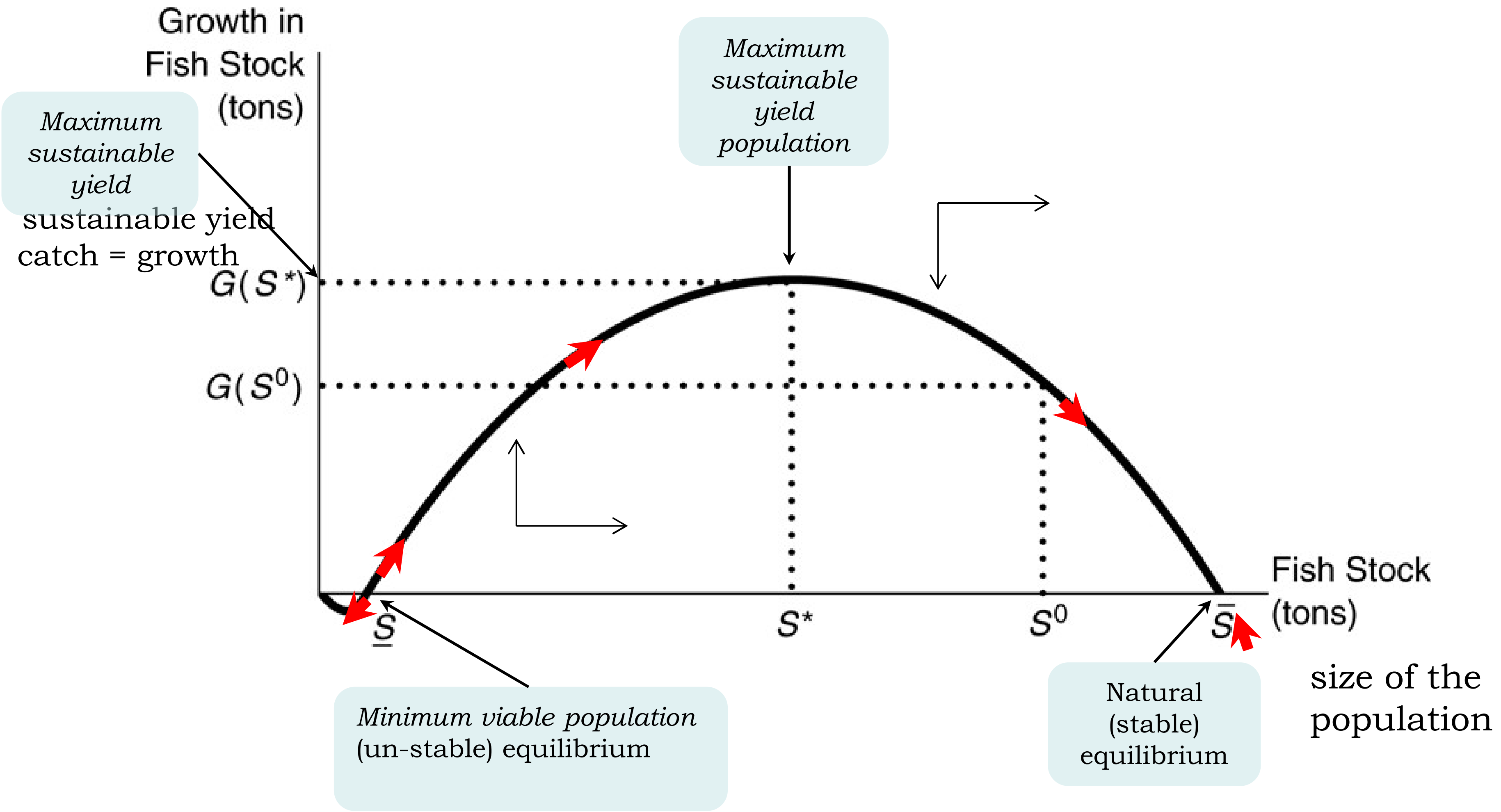
$$G(S)_t = gS_t\left(\frac{S_t}{S_{MIN}} - 1\right)\left(1 - \frac{S_t}{S_{MAX}}\right)$$

where I've chosen $g=0,07$, $S_{MIN}=0,3$ and $S_{MAX}=1$



* In population dynamics, depensation is the effect on a population (such as a fish stock) whereby, due to certain causes, a decrease in the breeding population (mature individuals) leads to reduced production and survival of eggs or offspring.

Fish Population and Growth



Bioeconomic equilibrium

- Definitions
- *Minimum viable population*, $\underline{S}$ or S_{MIN}, represents the level of population below which growth in population is negative (deaths and out-migration exceed births and in-migration)

- A catch level is said to represent a *sustainable yield whenever it equals the growth rate* of the population, since it can be maintained forever.

- *Maximum sustainable yield population*, S^*, *defined as the* population size that yields the maximum growth; hence, the maximum sustainable yield (catch) is equal to this maximum growth and it represents the largest catch that can be perpetually sustained.

- The sustainable yield is the growth in the biomass defined by the intersection of this line with the vertical axis. *For example,* $G(S_0)$ is the sustainable yield for population size S_0.

Economic model

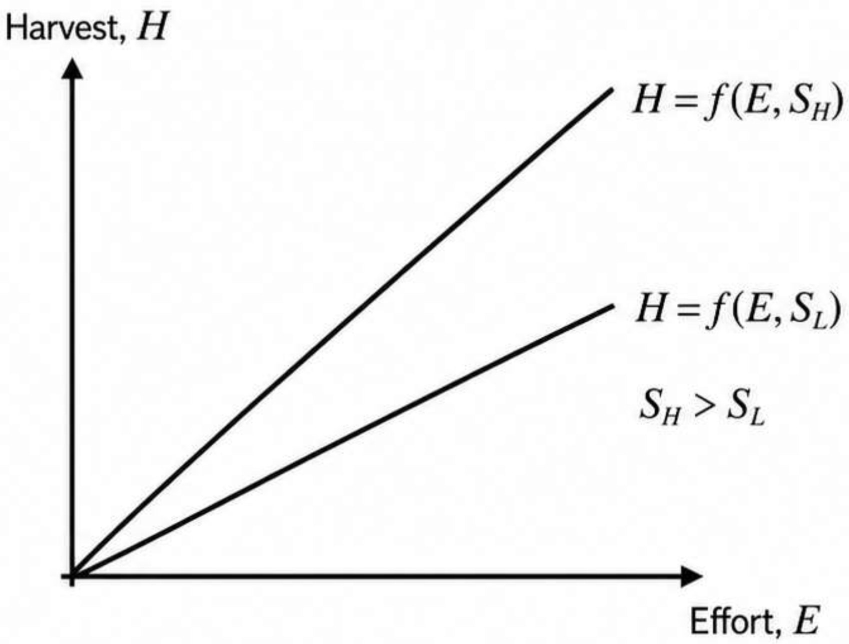
Harvest depends on stock size and fishing effort

- Harvest function: $H = f(E, S) = eES$
- E = fishing effort
- S = stock size
- e = catchability coefficient
- More effort raises harvest; a larger stock makes effort more productive.
- Short-run view: for a given stock S, harvest increases with effort E.
- Cost of effort: $C = wE$
- Profit: $\pi = pH - C$

Intuition

1. If stock is abundant, each unit of effort catches more.
2. If stock is scarce, the same effort catches less.
3. Economic decisions compare revenue from harvest with the cost of effort.

Harvest for different stock levels



Higher stock shifts the harvest function upward

Key idea: harvest rises with effort, but for any given effort it is higher when the stock is larger.

Economic model

- Define first harvest level: we assume that it is a function of the size of the population and the amount of effort expended. The commonly used form is:

$$H=f(E,S)=eES$$

where

e a constant (known as the "catchability coefficient"), and

E the level of effort

Examples of effort are hours of trawling, number of gillnets and number of long-line hooks. Effort is produced by optimal use of inputs and is expressed in the production function (for an intermediate good) $E=g(\upsilon_1,\ldots,\upsilon_n)$, where E is effort and υ_i is factor $i=1,\ldots,n$.

- Note that the harvest function is a short-run (static) production function in the sense that it is valid for a given stock level at any point in time, without any feedback from effort to stock

Economic model

- Define costs: Assuming a constant marginal cost of effort, w, allows us to define total cost as:

$$C = wE.$$

- Define economic profit: the difference between the total revenue from the sale of harvested resources and the total cost incurred in resource harvesting.

$$NB = B - C = PeES - wE$$

where

P is the price, assumed to be a constant

Bioeconomic equilibrium

- Biological equilibrium occurs where the resource stock is constant through time (that is, it is in a steady state). This requires that the amount being harvested equals the amount of net natural growth: $G = H$

$$gS\left(1-\frac{S}{S_{MAX}}\right)=eES \Rightarrow S=S_{MAX}\left(1-\frac{eE}{g}\right)$$

- Using S = H/eE from the harvest equation, we solve for H:

$$\frac{H}{eE}=S_{MAX}\left(1-\frac{eE}{g}\right)\Rightarrow H_s=eES_{MAX}-\frac{e^2E^2S_{MAX}}{g}$$

- It is now possible to find the maximum sustainable effort level by taking the derivative of the right-hand side of the above equation with respect to effort (E) and setting the result equal to zero.

$$eS_{MAX}-2\frac{e^2ES_{MAX}}{g}=0\Rightarrow E_{msy}=\frac{g}{2e}$$

where, E_{msy}: level of effort consistent with the maximum sustained yield.

Bioeconomic equilibrium

At equilibrium, harvest equals biological growth

- **Biological equilibrium:** the stock remains constant over time (steady state).
- **Equilibrium condition:** harvest equals net natural growth $G = H$
- Using logistic growth and the harvest function:

$$gS\left(1 - \frac{S}{S_{\max}}\right) = eES$$

$$S = S_{\max}\left(1 - \frac{eE}{g}\right)$$

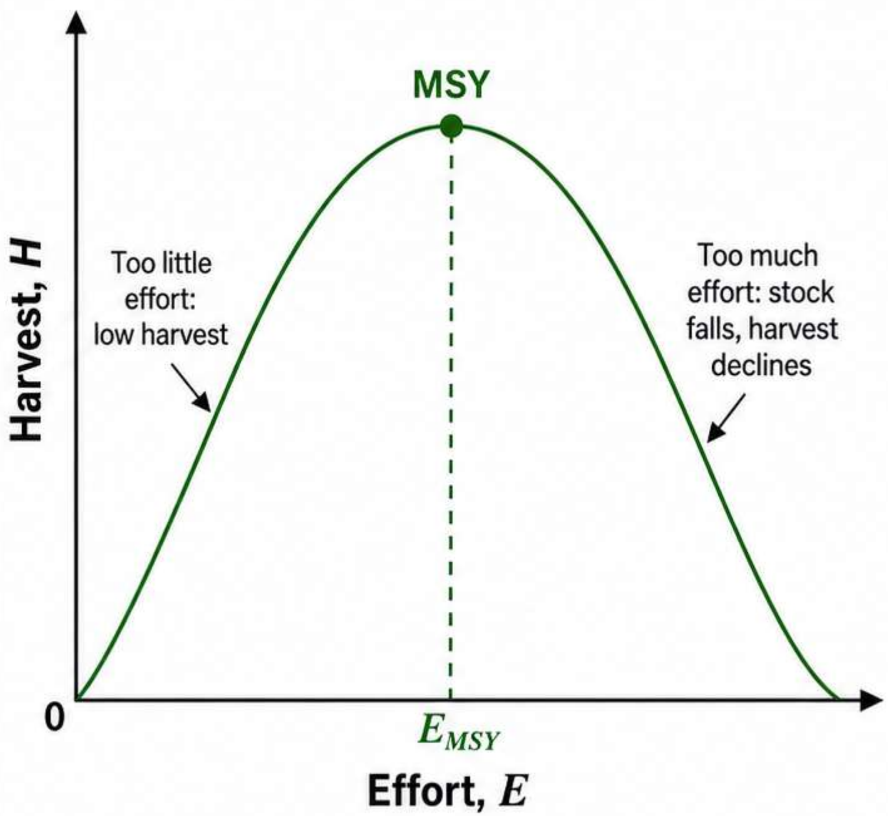
- Substituting into harvest gives the sustainable-yield function:

$$H = eES$$

$$H(E) = eES_{\max} - \frac{e^2E^2S_{\max}}{g}$$

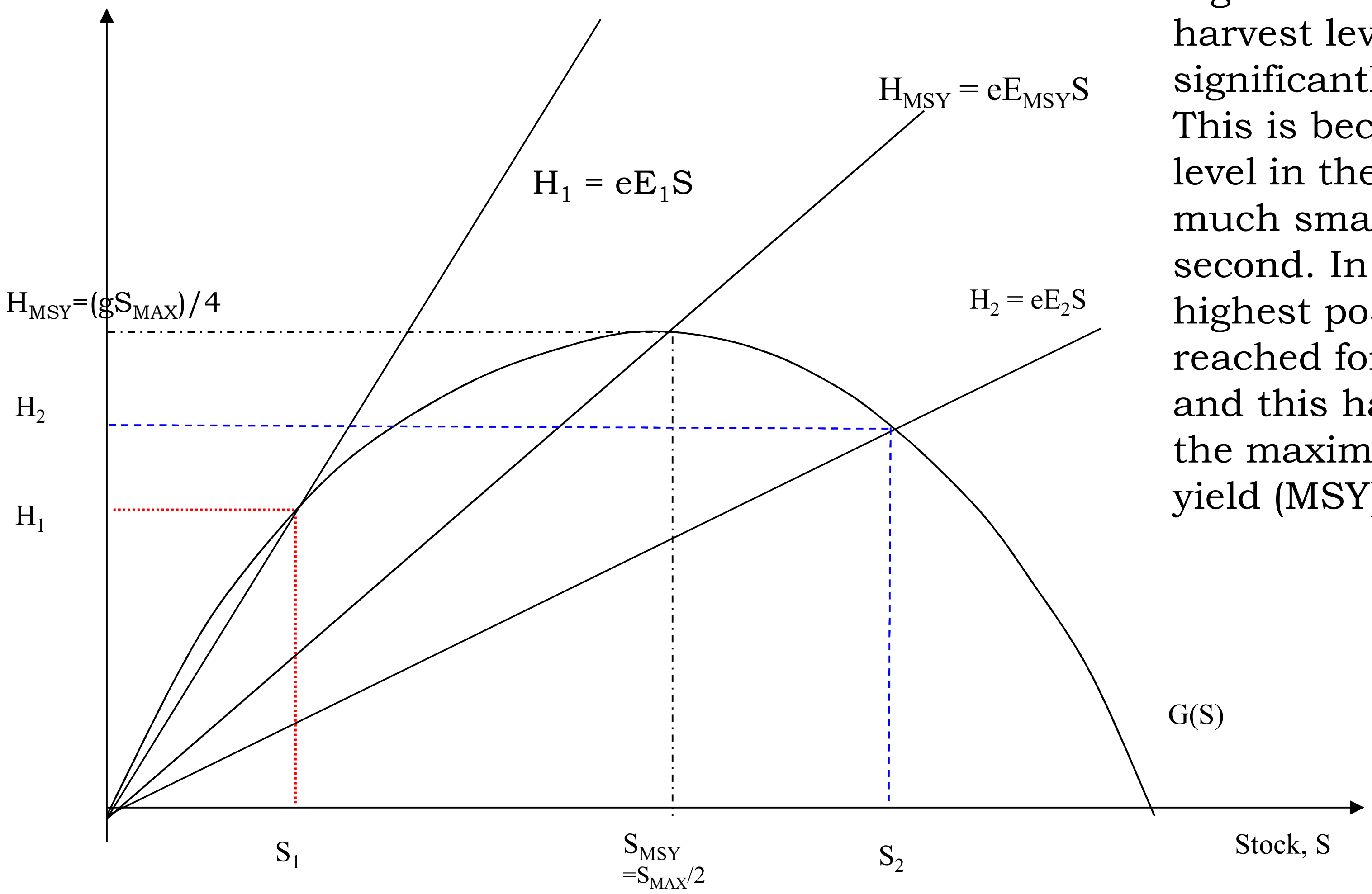
- Maximum sustainable yield occurs where $\frac{dH}{dE} = 0$, so $E_{MSY} = \frac{g}{2e}$

Sustainable yield as a function of effort



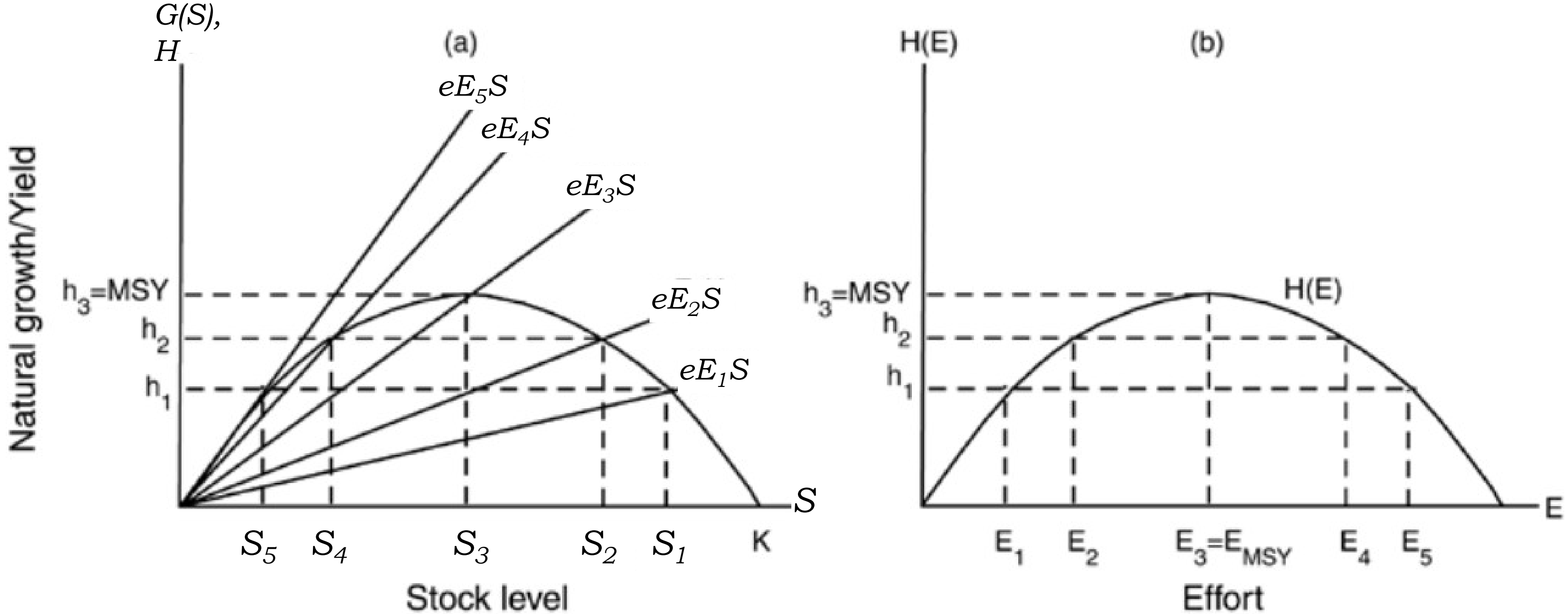
Key idea: sustainable harvest first rises with effort, reaches a maximum at E_{MSY}, and then falls as higher effort reduces the stock.

Steady-state equil, fish harvests and stocks at various effort levels



An effort E_1 which is much higher than E_2 gives harvest level H_1 that is significantly lower than H_2. This is because the stock level in the first case is much smaller than in the second. In the Figure the highest possible harvest is reached for effort level E_{MSY} and this harvest is called the maximum sustainable yield (MSY).

Steady-state equil, fish harvests and stocks at various effort levels

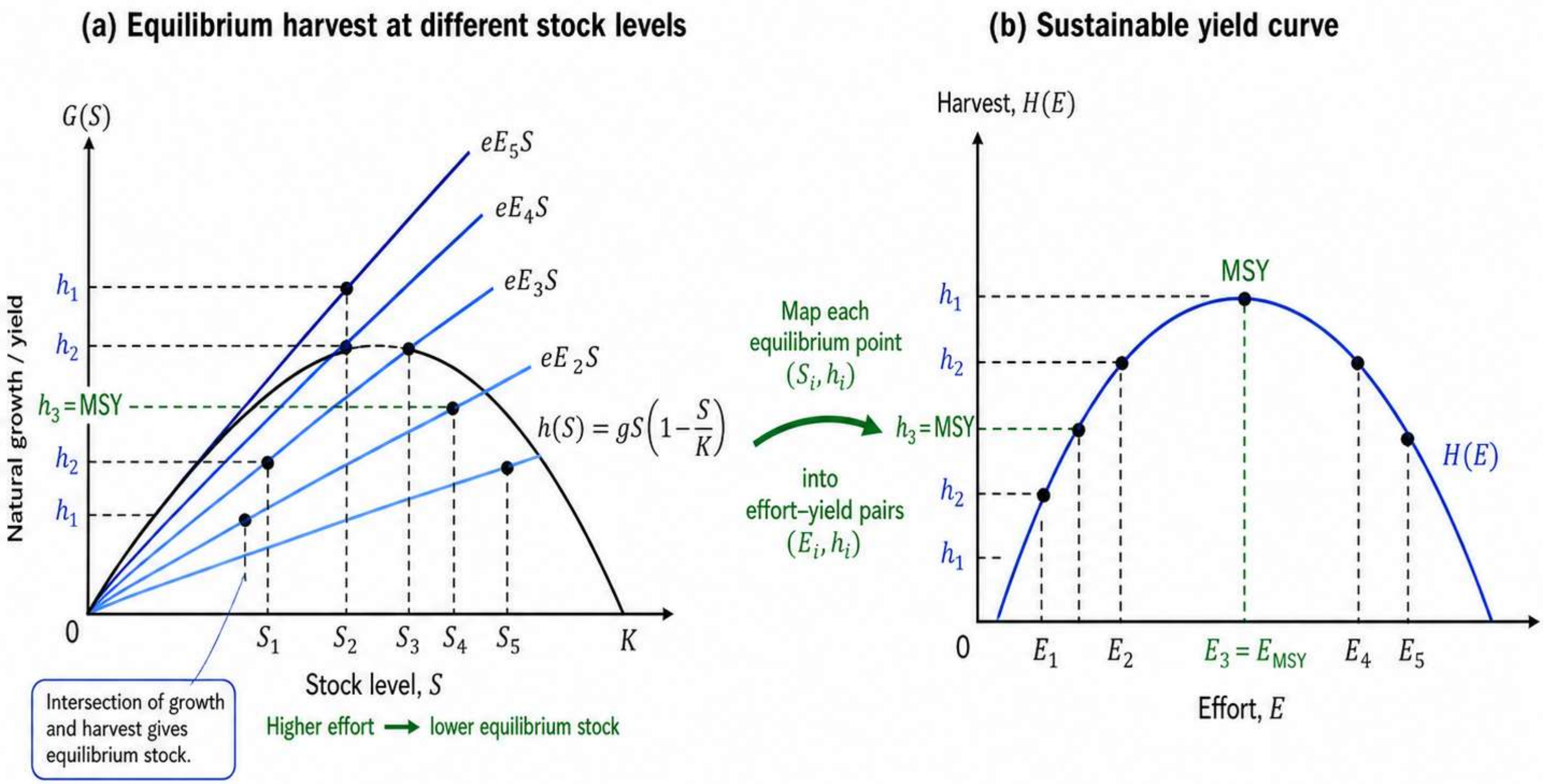


The natural-growth stock-level curve in panel (a) has been transformed into a sustainable harvest-effort curve in panel (b). The H(E) curve is also called the sustainable yield curve and it connects the long-run harvest potential to fishing effort. This harvest-effort curve has the same form as the growth curve in this case since the short-run harvest function is linear in both effort and stock.

It is important to note the difference between the short-run harvest function $H=f(E,S)$, depicted as straight lines in panel (a) and the sustainable yield curve *H(E)*, in panel (b). The former is valid for any combination of effort, E, and stock, S, at any time, whereas the latter is the long-run equilibrium harvest for given levels of effort. The sustainable yield curve is conditional on equilibrium harvest.

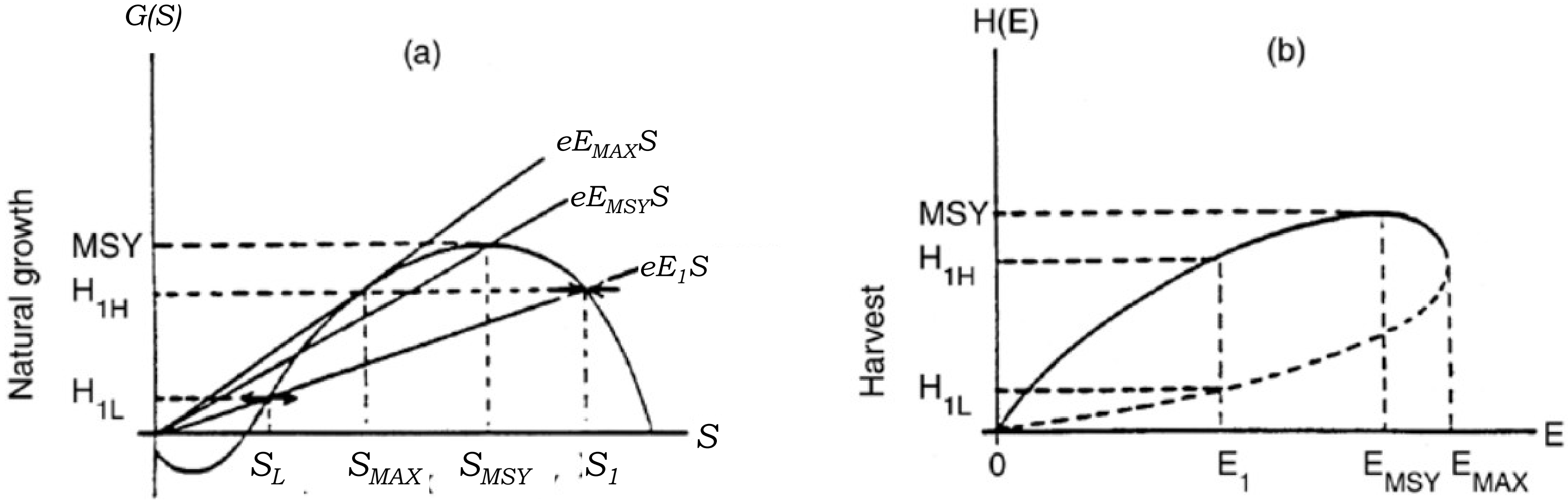
From stock equilibrium to the sustainable-yield curve

How equilibrium stock levels map into harvest as effort changes



Key idea: each effort level determines a harvest line in stock space;
the equilibrium harvest from those intersections traces out the sustainable-yield curve $H(E)$.

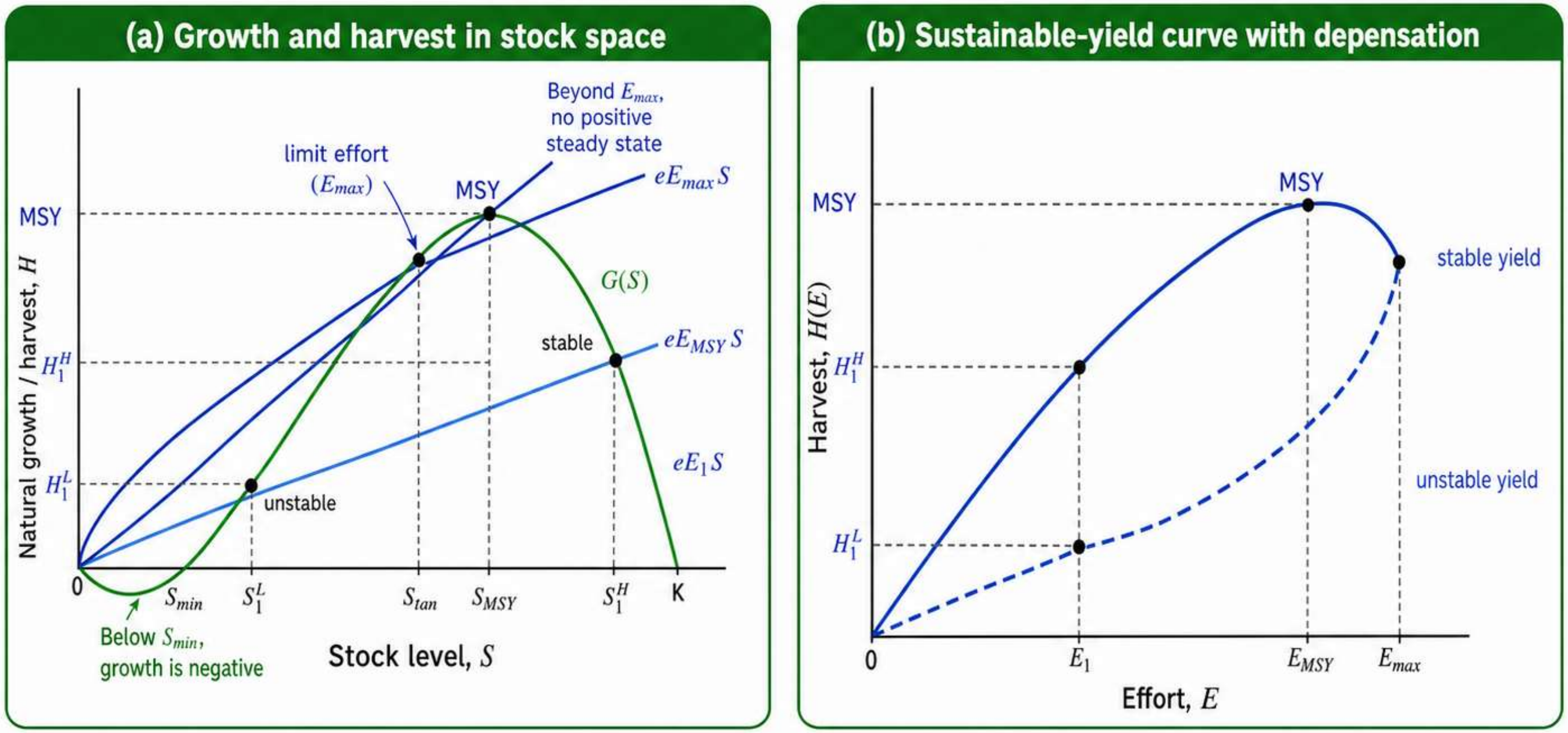
Steady-state equil, fish harvests and stocks at various effort levels



Panel (b) shows that the harvest curve is double, with an upper and a lower branch for each value of effort between E_D and E_{MAX}. This is due to the existence of two intersection points between each of the linear harvest curves and the growth curve, as shown in panel (a). There is, however, a significant difference between the two branches of the yield curve. The upper part constitutes stable points of harvesting whereas the lower part constitutes unstable harvesting. Example: harvest curve for effort E_1 intersects with the growth curve for two stock levels, the low one S_L and the high one S_1 in panel (a). For stock levels lower than S_L the harvest curve is above the growth curve and the natural growth is too small to compensate for the harvest. This implies that the stock will decrease to zero if effort E_1 is maintained over a sufficiently long period of time. Thus, S_L is an unstable equilibrium for the stock harvested by effort E_1.

Steady-state equilibrium with depensation

Stable and unstable harvest–stock outcomes at different effort levels



Depensation creates a lower unstable branch: if stock falls too far, the system can collapse even at the same effort.

Key idea: with depensation, one effort level can imply two equilibria: a low-stock unstable yield and a high-stock stable yield. At E_{max} the two branches meet; beyond E_{max} no positive steady-state harvest exists.

Economic models of a fishery

- Biological populations belong to a class of renewable resources we will call *interactive resources, wherein the size of the resource stock (population) is* determined jointly by biological considerations and by actions taken by society.
- We will examine two types of frameworks:
- Open access fishery. A firm,
  - enters if profit per boat is positive
  - leaves if profit per boat is negative
  - in steady-state, $R = C$ (revenue = costs)
- Closed access (private property) fishery
  - Static (single period) model: Choose effort to maximise profits in any 'representative' single period (select E to maximise $Profit = R - C$)
  - Dynamic (intertemporal) model: Choose a path of effort over time to maximise the wealth of the firm (maximise the present value of the fishery)

Efficient Sustainable Yield

- The maximum sustainable yield is not synonymous with efficiency. Efficiency is associated with maximizing the *net benefit from the use of* the resource: we must include costs and benefits of harvesting.

- The complete model has two components:

1. The previously described biological sub-model, describing the natural growth process of the fishery;
2. an economic sub-model, describing the economic behaviour of the fishing boat owners.

Static vs dynamic approach

- We shall be looking for two kinds of solutions.
- The first is its equilibrium (or steady-state) solution. This consists of a set of circumstances in which the resource stock size is unchanging over time (a biological equilibrium) *and* the fishing fleet is constant with no net inflow or outflow of vessels (an economic equilibrium). Because the steady-state equilibrium is a joint biological–economic equilibrium, it is often referred to as *bioeconomic* equilibrium.

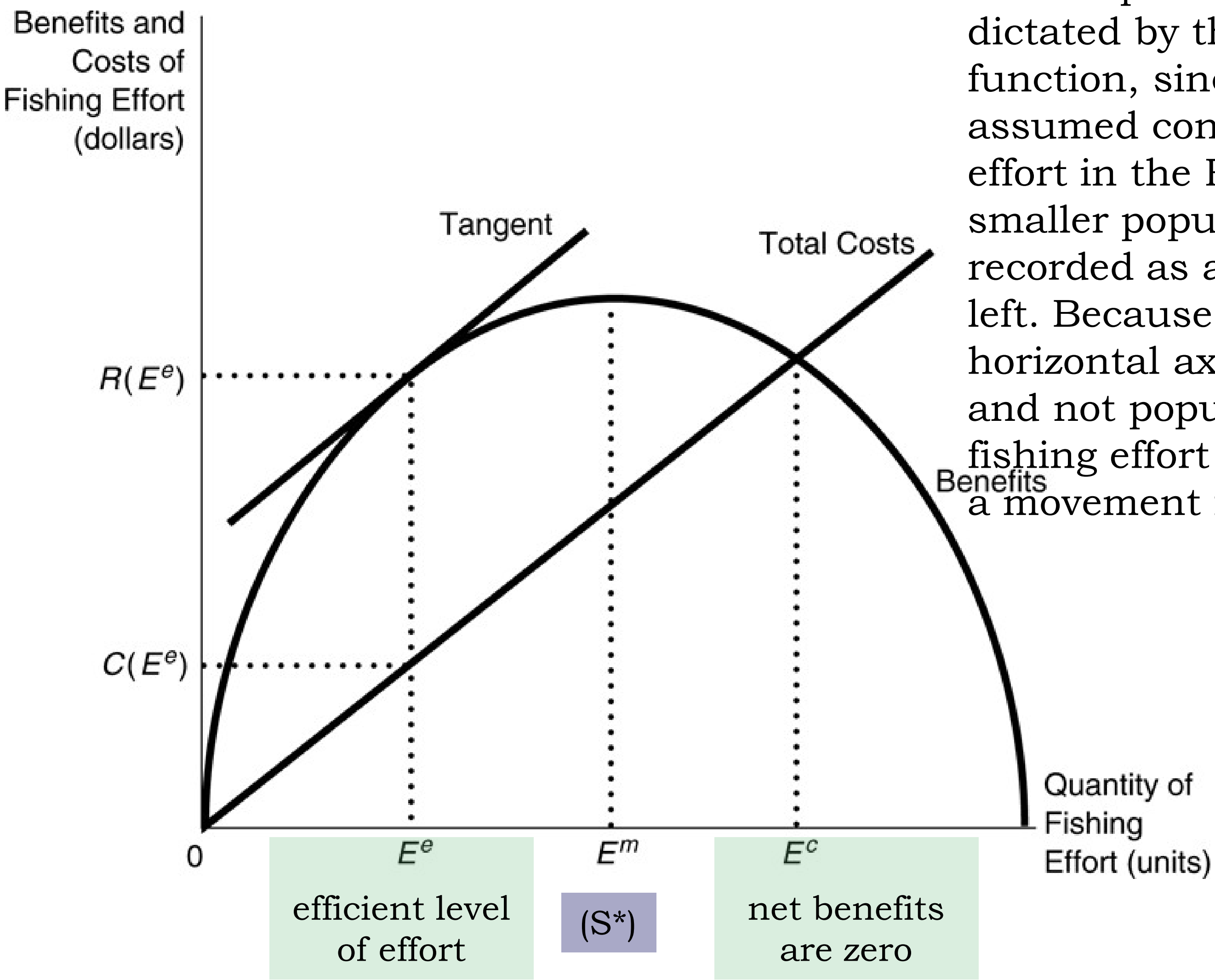
- The second kind of solution we shall be looking for is the adjustment path towards the equilibrium, or from one equilibrium to another as conditions change. In other words, our interest also lies in the dynamics of renewable resource harvesting. This has important implications for whether a fish population may be driven to exhaustion, and indeed whether the resource itself could become extinct.

Efficient Allocations

- Assumptions of the economic model are:
  - The price of fish is constant and does not depend on the amount sold.
  - The marginal cost of a unit of fishing effort is constant.
  - The amount of fish caught per unit of effort expended is proportional to the size of the fish population.

- We first define the static efficient sustainable yield (i.e. without worrying about discounting).
- The *static efficient sustainable yield* is the catch level that, if maintained perpetually, would produce the largest annual net benefit. [*The dynamic efficient sustainable yield, incorporates discounting*].

Efficient Sustainable Yield for a Fishery



The shape of the revenue function is dictated by the shape of the biological function, since the price of fish is assumed constant. Increasing fishing effort in the Figure would result in smaller population sizes and would be recorded as a movement from right to left. Because the variable on the horizontal axis in the Figure is effort, and not population, an increase in fishing effort is recorded as a movement from left to right.

Profit maximizing solution

- A private-property fishery has the following three characteristics:
  1. There is a large number of fishing firms, each behaving as a price-taker and so regarding price as being equal to marginal revenue. It is for this reason that the industry is often described as being competitive.
  2. Each firm is wealth maximizing.
  3. There is a particular structure of well-defined and enforceable property rights to the fishery, such that owners can control access to the fishery and appropriate any rents that it is capable of delivering.

- What exactly is this particular structure of private property rights? Within the literature there are several (sometimes implicit) answers to this question. We shall outline two of them.
  1. A private property fishery refers to the harvesting of a single species from lots of different biological fisheries, fishing grounds. Each fishing ground is owned by a fishing firm. That fishing firm has private property rights to the fish which are on that fishing ground currently and at all points in time in the future. All harvested fish, however, sell in one aggregate market at a single market price.
  2. The fishery as being managed by a single entity which controls access to the fishery and coordinates the activity of individual operators to maximize total fishery profits (or wealth). Nevertheless, harvesting and pricing behaviour are competitive rather than monopolistic.

Bioeconomic equilibrium

- Economic equilibrium is reached when the profit is maximized (given that private property rights have been allocated and can be monitored and enforced). That is, we will be looking for the level of effort that maximizes *NB = B – C, with* $H=H_s$,

$$NB_s = PH_s - wE = PeES_{MAX} - \frac{Pe^2E^2S_{MAX}}{g} - wE$$

- Since the efficient sustained effort level is the level that maximizes the above equation, we can derive it by setting its derivative with respect to effort (E) equal to zero:

$$PeS_{MAX} - 2\frac{Pe^2ES_{MAX}}{g} - w = 0 \Rightarrow E^* = \frac{g}{2e}\left(1 - \frac{w}{PeS_{MAX}}\right)$$

- Note first, that this effort level is smaller than that needed to produce the maximum sustainable yield.
- Notice also that when this condition is satisfied, $dE/dt = 0$ and so effort is constant at its equilibrium (or steady-state) level $E = E^*$.

Bioeconomic equilibrium

- Substituting E^* into the biological equilibrium $G = H$, we solve for S^*

$$S^* = S_{MAX}\left(1 - \frac{eE^*}{g}\right) = S_{MAX}\left(1 - \frac{1}{2} + \frac{w}{1PeS_{MAX}}\right)$$

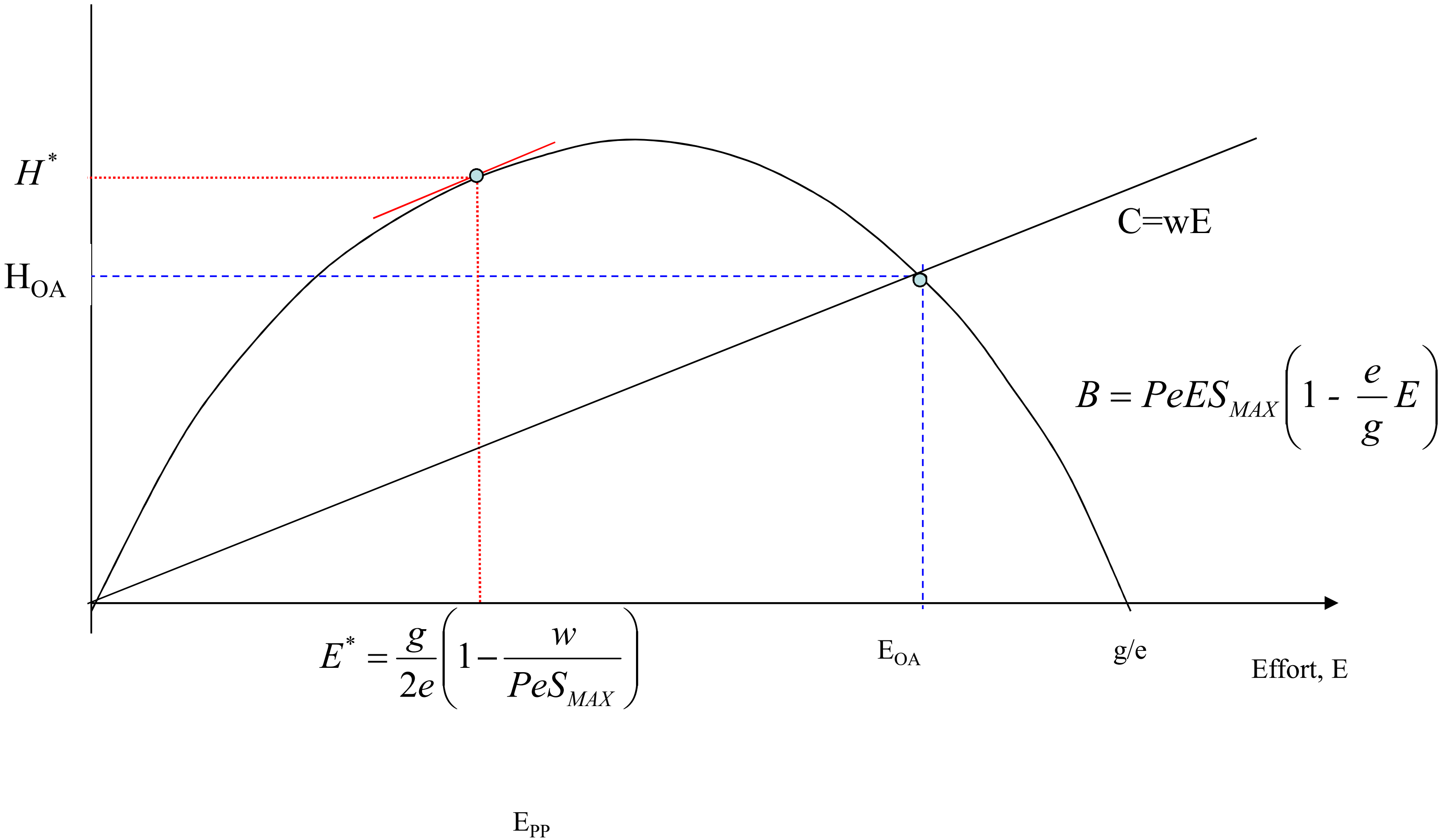
$$\Rightarrow S^* = \frac{PeS_{MAX} + w}{2Pe}$$

- And finally, substituting S* and E* into $H=eES$, we derive H*:

$$H^* = eE^*S^* \Rightarrow H^* = e\frac{g}{2e}\left(1 - \frac{w}{PeS_{MAX}}\right)\frac{PeS_{MAX} + w}{2Pe}$$

$$\Rightarrow H^* = \frac{g}{4}\left(S_{MAX} - \frac{w^2}{P^2e^2S_{MAX}}\right)$$

Steady-state equilibrium yield-effort relationship



Appropriability and Market Solutions

- A sole owner of a fishery would have a well-defined property right to the fish and would want to maximize his or her profits.
  - Profit maximization will lead to the static-efficient sustainable yield.
- Ocean fisheries are typically open-access resources. Thus, no single fisherman can keep others from exploiting the fishery.

Open access solution

- Determination of fishing effort under conditions of open access.

- Assuming free entry and exit into and from the industry (there are no barriers to entry or restrictions for changing their level of harvesting effort), an increase in the level of effort is expected as long as there are positive economic profits, and vise versa, that is, if firms cannot cover their costs will leave the fishery.

- We can represent the entry-exit process algebraically by the equation $dE/dt = \delta \cdot NB$, where δ is a positive parameter indicating the responsiveness of industry size (expressed by the level of effort) to industry profitability.

- When economic profit (NB) is positive, firms will enter the industry; and when it is negative they will leave. The magnitude of that response, for any given level of profit or loss, will be determined by δ.

Bioeconomic open-access equilibrium

- We can now move from the efficient to the free, or open-access equilibrium. Free access implies zero profits, so that there is no longer an incentive for entry into or exit from the industry, nor for the fishing effort on the part of existing fishermen to change, that is, *NB=0*.

$$NB_s = 0 \Rightarrow PH_s - wE = 0 \Rightarrow PeES_{MAX} - \frac{Pe^2E^2S_{MAX}}{g} - wE = 0$$

- Rearranging terms yields

$$E^c = \frac{g}{e}\left(1 - \frac{w}{PeS_{MAX}}\right)$$

- Note that this exceeds the efficient sustained level of effort. It may or may not be larger than the level of effort needed to produce the max. sustained yield. That comparison depends on the specific values of the parameters.

- Similarly to the efficient case we can derive:

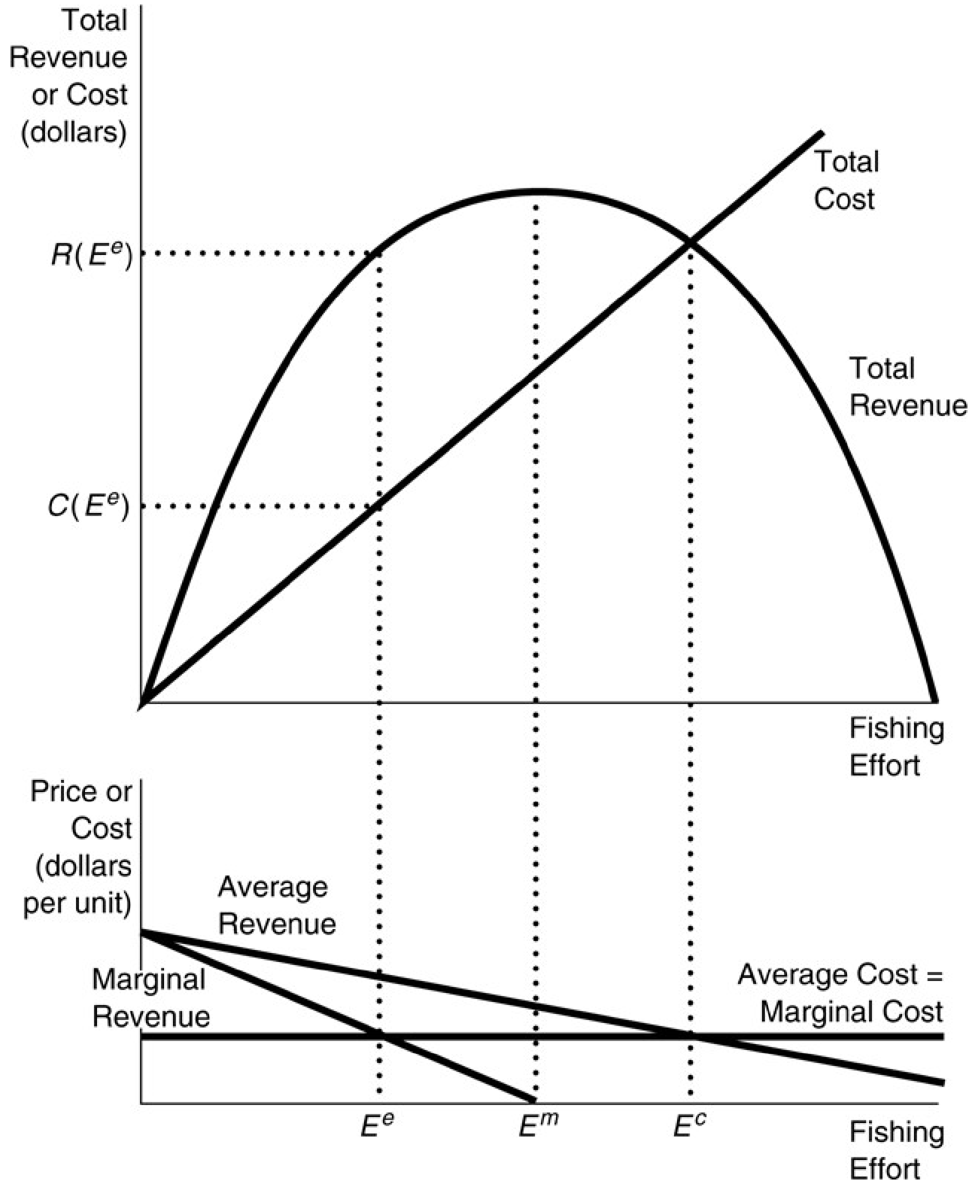
$$S^c = \frac{w}{Pe} \qquad H^c = \frac{gw}{Pe}\left(1 - \frac{w}{PeS_{MAX}}\right)$$

Market Allocation in a Fishery

A sole owner would want to maximize her profits. That is she will increase fishing effort until marginal revenue equals marginal cost. This occurs at effort level E^e, *the static* efficient sustainable yield, and yields positive profits equal to the difference between $R(E^e)$ *and* $C(E^e)$.

Ocean fisheries are typically open-access resources—no one exercises complete control over them. Thus, no fisherman can exclude others from exploiting the fishery.

Open-access resources create two kinds of external costs: a contemporaneous external cost and an intergenerational external cost.



An example

- Lets assume the following values for the model's parameters:
- *g=0,15*
- $S_{MAX}=1$
- *e=0,015*
- *P=200*
- *w=0,6*

- Then, we can derive the restricted (closed) access static solution:

$$E^* = \frac{g}{2e}\left(1-\frac{w}{PeS_{MAX}}\right) = \frac{0,15}{2(0,015)}\left(1-\frac{0,6}{200(0,015)1}\right) = \frac{10}{2}0,8 = 4$$

$$S^* = \frac{PeS_{MAX}+w}{2Pe} = \frac{200(0,015)1+0,6}{2(200)0,015} = \frac{3,6}{6} = 0.6$$

$$H^* = \frac{g}{4}\left(S_{MAX}-\frac{w^2}{P^2e^2S_{MAX}}\right) = \frac{0,15}{4}\left(1-\frac{(0,6)^2}{(200)^2(0,015)^2 1}\right) = 0,0375(0,96) = 0,036$$

An example

- Lets assume the following values for the model's parameters:
- $g=0,15$
- $S_{MAX}=1$
- $e=0,015$
- $P=200$
- $w=0,6$

- And also the open access static solution:

$$E^c = \frac{g}{e}\left(1-\frac{w}{PeS_{MAX}}\right) = \frac{0,15}{(0,015)}\left(1-\frac{0,6}{200\,(0,015)1}\right) = 10(0,8) = 8$$

$$S^c = \frac{w}{Pe} = \frac{0,6}{200(0,015)} = 0,2$$

$$H^c = \frac{gw}{Pe}\left(1-\frac{w}{PeS_{MAX}}\right) = \frac{0,6(0,15)}{200(0,015)}(0,8) = 0,024$$

Comparative statics for the static open access fishery model

- It is instructive to inspect how the steady state equilibrium levels of effort, stock and harvest in an open access fishery regime change in response to changes in the parameters or exogenous variables of that model.

- Just before we showed that for a particular illustrative (or baseline) set of parameter values, the steady state equilibrium magnitudes of stock, effort and harvest were $S^c = 0.2$, $E^c = 8.0$ and $H^c = 0.024$ respectively. But we would also like to know how the steady state equilibrium values would change in response to changes in the model parameters. This can be established using comparative static analysis.

- Comparative static analysis is undertaken by obtaining the first-order partial derivatives of each of these three equations with respect to a parameter or exogenous variable of interest and inspecting the resulting partial derivative.

Comparative statics for the static open access fishery model

	P	w	e	g
S^*	–	+	–	0
E^*	+	–	?	+
H^*	?	?	?	+

Efficient Allocations

The lower the extraction costs, and the higher the discount rate, the more likely it is that the dynamic efficient level of effort will exceed the level of effort associated with the maximum sustainable yield.

Dynamic Efficient Sustainable Yield

- The dynamic-efficient sustainable yield incorporates discounting.
  - The dynamic efficient sustainable yield will equal the static efficient sustainable yield if the discount rate equals zero.
  - Higher discount rates mean higher costs (foregone current income) to the resource owner of maintaining the stock.
  - With an infinite discount rate, net benefits equal zero.
  - Extinction could occur if the growth rate is lower than the discount rate and if the costs of extracting the last unit are sufficiently low.

The PV-maximizing fishery model

- The present-value-maximizing fishery model generalizes the model of the static private-property fishery, and in doing so provides us with a sounder theoretical basis and a richer set of results.
- The essence of this model is that a rational private-property fishery will organise its harvesting activity so as to maximize the discounted present value (PV) of the fishery.
- This section specifies the present-value-maximizing fishery model and describes and interprets its main results. Full derivations have been placed in Appendix 17.3.
- The individual components of our model are very similar to those of the static private fishery model. However, we now bring time explicitly into the analysis by using an intertemporal optimization framework.
- Initially we shall develop results using general functional forms. Later in this section, solutions are obtained for the specific functions and baseline parameter values assumed earlier.

The PV-maximizing fishery model

- To facilitate this, we specify fishing costs as a function of the quantity harvested and the size of the fish stock.

  $C_t = C(H_t, S_t) \qquad C_H > 0, C_S < 0$

- The initial population of fish is S_0, the natural growth of which is determined by the function $G(S)$.
- The fishery owners select a harvest rate for each period over the relevant time horizon (here taken to be infinity) to maximise the present value (or wealth) of the fishery, given an interest rate i.

  $$\text{Max} \int_0^{\infty} \{PH_t - C(H_t, S_t)\} e^{-it} \, \mathrm{d}t$$

  subject to

  $$\frac{\mathrm{d}S}{\mathrm{d}t} = G(S_t) - H_t$$

  and initial stock level $S(0) = S_0$.

The PV-maximizing fishery model

The necessary conditions for maximum wealth include

$$p_t = P - \frac{\partial C(H,S)}{\partial H_t}$$

$$\frac{\mathrm{d}p_t}{\mathrm{d}t} = ip_t - p_t \frac{\mathrm{d}G(S)}{\mathrm{d}S_t} + \frac{\partial C(H,S)}{\partial S_t}$$

- It is very important to distinguish between upper-case *P* and lower-case *p*.
- *P* is the market, or landed, or gross price of fish; it is, therefore, an observable quantity. As the market price is being treated here as an exogenously given fixed number, no time subscript is required on *P*.
- In contrast, lower-case *pt* is a shadow price, which measures the contribution to wealth made by an additional unit of fish stock at the wealth-maximizing optimum. It is also known as the net price of fish, and also as unit rent.

The PV-maximizing fishery model

Three properties of the **net price** deserve mention.

1. First, it is typically an unobservable quantity.
2. Second, like all shadow prices, it will vary over time, unless the fishery is in steady-state equilibrium. In general, therefore, it is necessary to attach a time label to net price.
3. The third property concerns an equivalence between the net price equations for the renewable and non-renewable resource cases.

- The first equation defines the net price of the resource (p_t) as the difference between the market price and marginal cost of an incremental unit of harvested fish.
- The second, differential equation governs the behaviour over time of the net price, and implicitly determines the harvest rate in each period.
- Note that if growth is set to zero (as would be the case for a non-renewable resource) and the stock term in the cost function is not present (so that the size of the resource stock has no impact on harvest costs) then the net price equation for renewable resources collapses to a special case that is identical to its counterpart for a non-renewable resource

The PV-maximizing fishery model

In a steady state all variables are unchanging with respect to time, which implies that $dp/dt = 0$ and also that $G(S) = H$. Hence the optimising conditions 17.29 and 17.30 collapse to the simpler forms

$$p = P - \frac{\partial C(H,S)}{\partial H} \tag{17.31}$$

$$ip = p\frac{dG(S)}{dS} - \frac{\partial C(H,S)}{\partial S} \tag{17.32}$$

Interpretation

A decision about whether to defer some harvesting until the next period is made by comparing the marginal costs and benefits of adding additional units to the resource stock. **By not harvesting an incremental unit this period, the fisher incurs an opportunity cost that consists of the foregone return by holding a stock of unharvested fish. The marginal cost of the investment is *ip*, *as* sale of one unit of the harvested fish would have led to a revenue net of harvesting costs (given by the net price of the resource, *p*) that could have earned the prevailing rate of return on capital, *i*. Since we are considering a decision to defer this revenue by one period, the present value of this sacrificed return is *ip*.**

The owner compares this marginal cost with the marginal benefit obtained by not harvesting the incremental unit this period. There are two categories of marginal benefit:

1. **As an additional unit of stock is being added, *total* harvesting costs will be reduced by the quantity $C_S = \partial C/\partial S$ (note that $\partial C/\partial S < 0$).**
2. **The additional unit of stock will grow by the amount dG/dS. The value of this additional growth is the amount of growth valued at the net price of the resource.**

The PV-maximizing fishery model

A present-value-maximising owner will add units of resource to the stock provided the marginal cost of doing so is less than the marginal benefit. That is:

$$ip < \frac{\mathrm{d}G}{\mathrm{d}S}p - \frac{\partial C}{\partial S}$$

This states that a unit will be added to stock provided its 'holding cost' (ip) is less than the sum of its harvesting cost reduction and value-of-growth benefits. Conversely, a present-value-maximising owner will harvest additional units of the stock if marginal costs exceed marginal benefits:

$$ip > \frac{\mathrm{d}G}{\mathrm{d}S}p - \frac{\partial C}{\partial S}$$

The natural rate of growth in the stock from a marginal change in the stock size

The value of the reduction in the harvesting cost from a marginal change in the stock size

Appropriability and Market Solutions

- Open-access creates two kinds of external costs:
  - **Contemporaneous external costs** are the costs imposed on the current generation from overfishing. Too many resources (boats, fishermen, etc.) are committed to fishing.
  - **Intergenerational external costs** are the costs imposed on the future generation from the exploitation of the stock today. Overfishing reduces stocks and thus future profits.

Appropriability and Market Solutions

- Unlimited access creates property rights that are not well-defined.

- With free-access, individual fishermen have no incentive to "save" the resource.

- Open-access and common-pool resources are not synonymous.
  - Not all common property resources allow unlimited access. Informal arrangements among those harvesting the common property resource, for example, can serve to limit access.

The dynamics of renewable resource harvesting

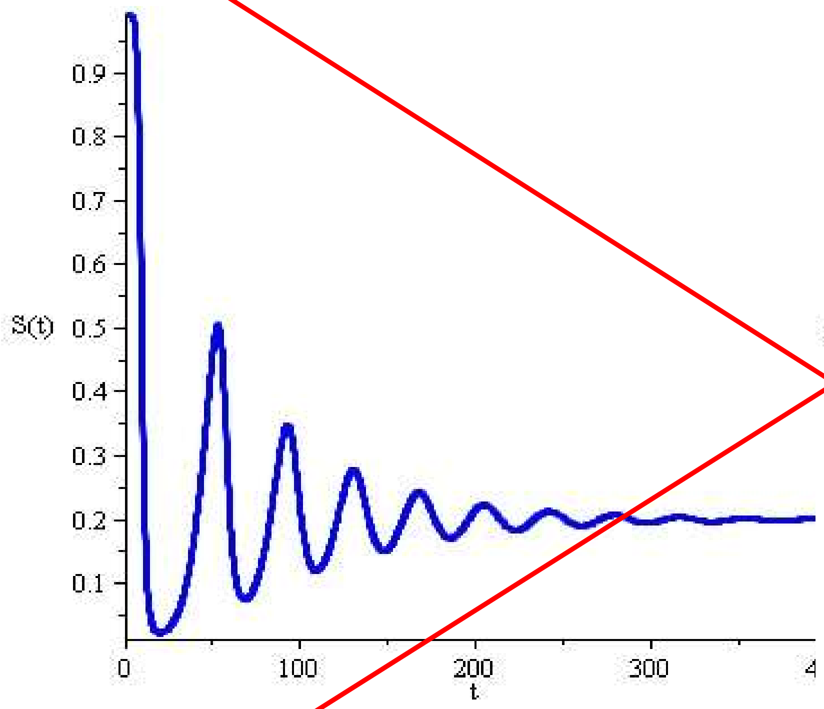
- Discussion so far has been exclusively about steady states: equilibrium outcomes which, if achieved, would remain unchanged provided that relevant economic or biological conditions remain constant.

- However, we may also be interested in the *dynamics* of resource harvesting.
  1. This would consider questions such as how a system would get to a steady state if it were not already in one, or whether getting to a steady state is even possible.
  2. In other words, dynamics is about transition or adjustment paths.
  3. Dynamic analysis might also give us information about how a fishery would respond, through time, to various kinds of shocks and disturbances.

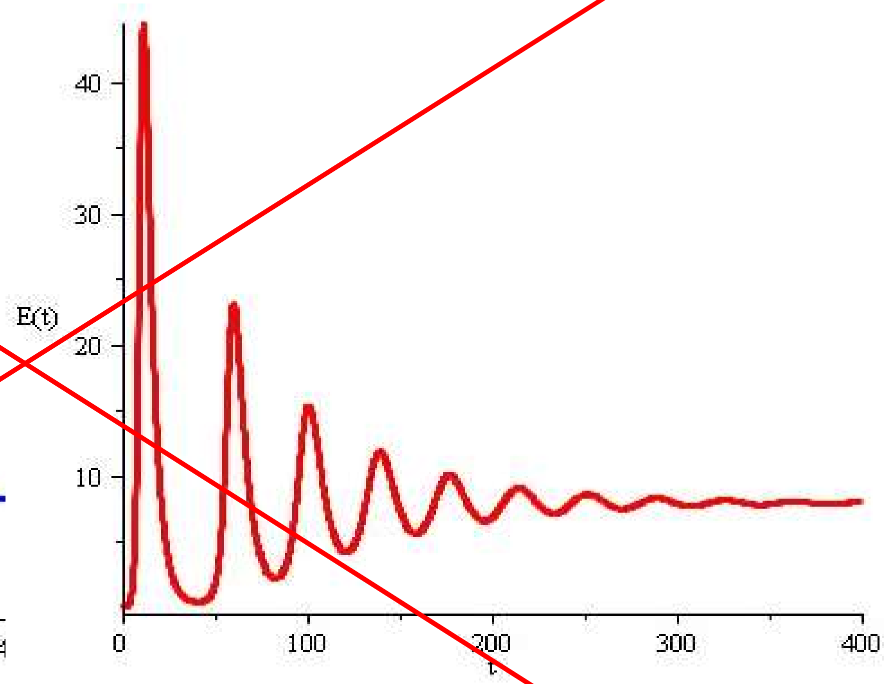
- The dynamics of the open access fishery model are driven by two differential equations, determining the instantaneous rates of change of S and E:

The net rate of change of the fish stock	$\frac{dS}{dt} = G(S) - H = g\left(1 - \frac{S}{S_{MAX}}\right)S - H$
The open-access entry rule	$\frac{dE}{dt} = \delta(PeES - wE)$

Stock and effort dynamic paths for the open access model

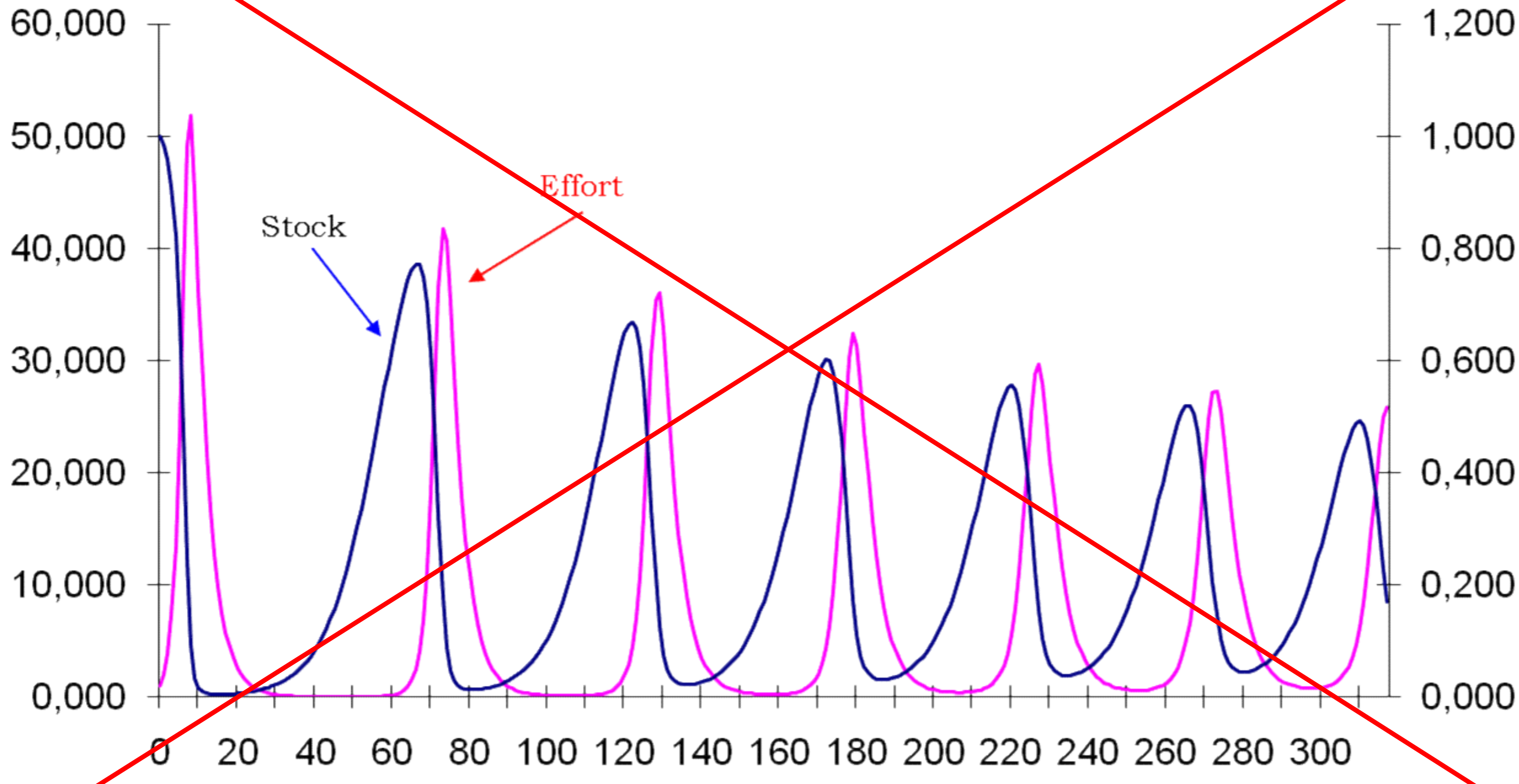


Rate of change of S



Rate of change of E

Stock and effort dynamic paths to illustrate their relative phasing.



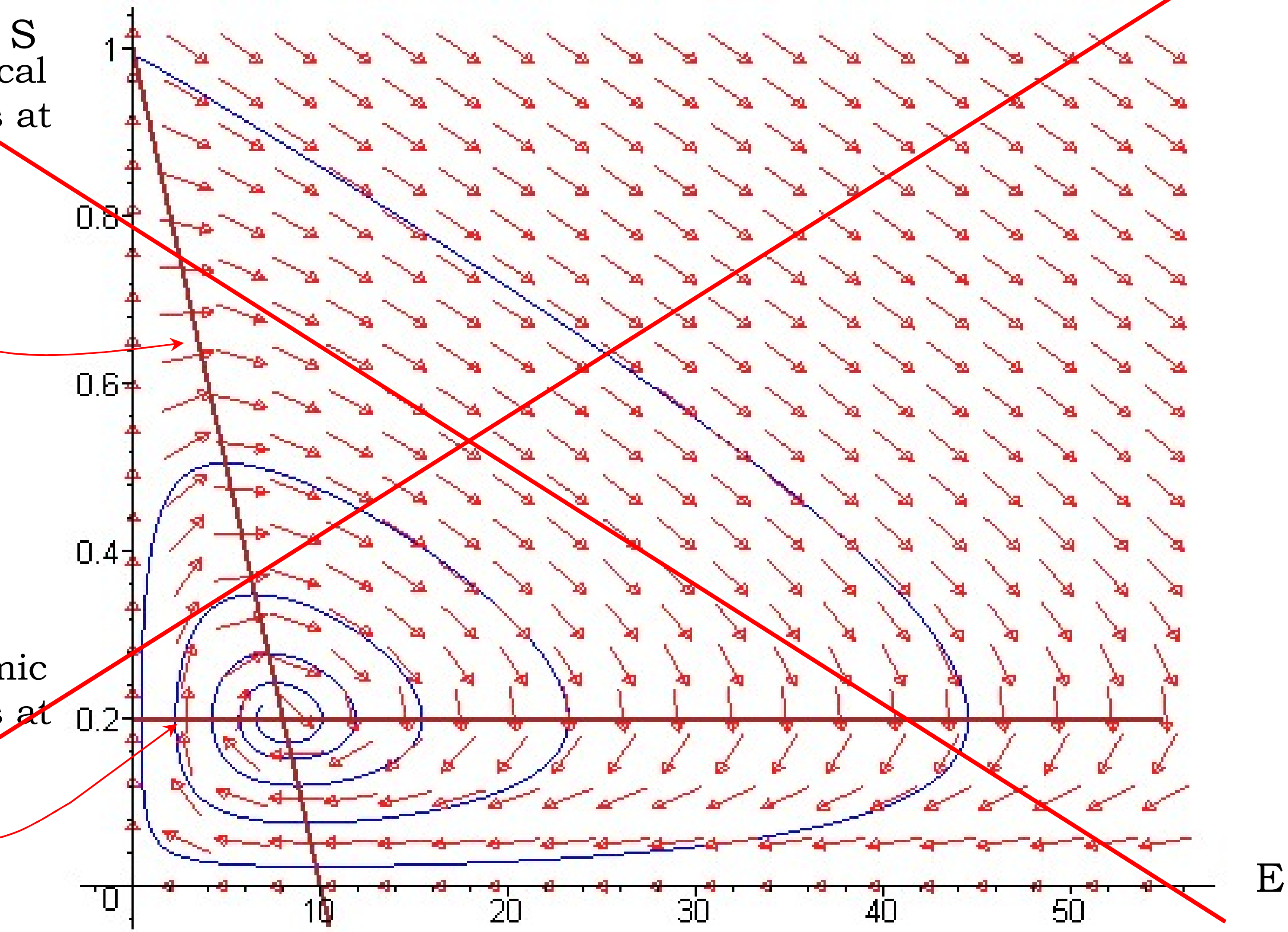
Phase-plane diagrams

- Another way of describing the information given in the previous Figure is in terms of a 'phase-plane' diagram. An example is shown in the following Figure.
- The axes define a space consisting of pairs of values for S and E.
- The steady-state equilibrium ($S^c = 0.2$ and $E^c = 8.0$) lies at the intersection of two straight lines the meaning of which will be explained in a moment.
- The adjustment path through time is shown by the line which converges through a series of diminishing cycles on the steady-state equilibrium.
- In the story we have just told, the stock is initially at 1 and effort begins at a small value (just larger than zero). Hence we begin at the top left point of the indicated adjustment path. As time passes, stock falls and effort rises – the adjustment path heads south-eastwards. After some time, the stock continues to fall but so too does effort – the adjustment path follows a south-west direction.

Phase-plane analysis of stock and effort dynamic paths for the illustrative model.

locus of all biological equilibrium points at which $G = H$, i.e. $dS/dt = 0$

locus of all economic equilibrium points at which profit=zero, i.e. $dE/dt = 0$



The phase-plane diagram also presents some additional information

- First, the arrows denote the directions of adjustment of *S* and *E* whenever the system is not in steady state, from any arbitrary starting point.
  - It is evident that the continuous-time version of the open-access model we are examining here *in conjunction with* the particular baselines parameter values being assumed has strong stability properties: irrespective of where stock and effort happen to be the adjustment paths will lead to the unique steady- state equilibrium, albeit through a damped, oscillatory adjustment process.

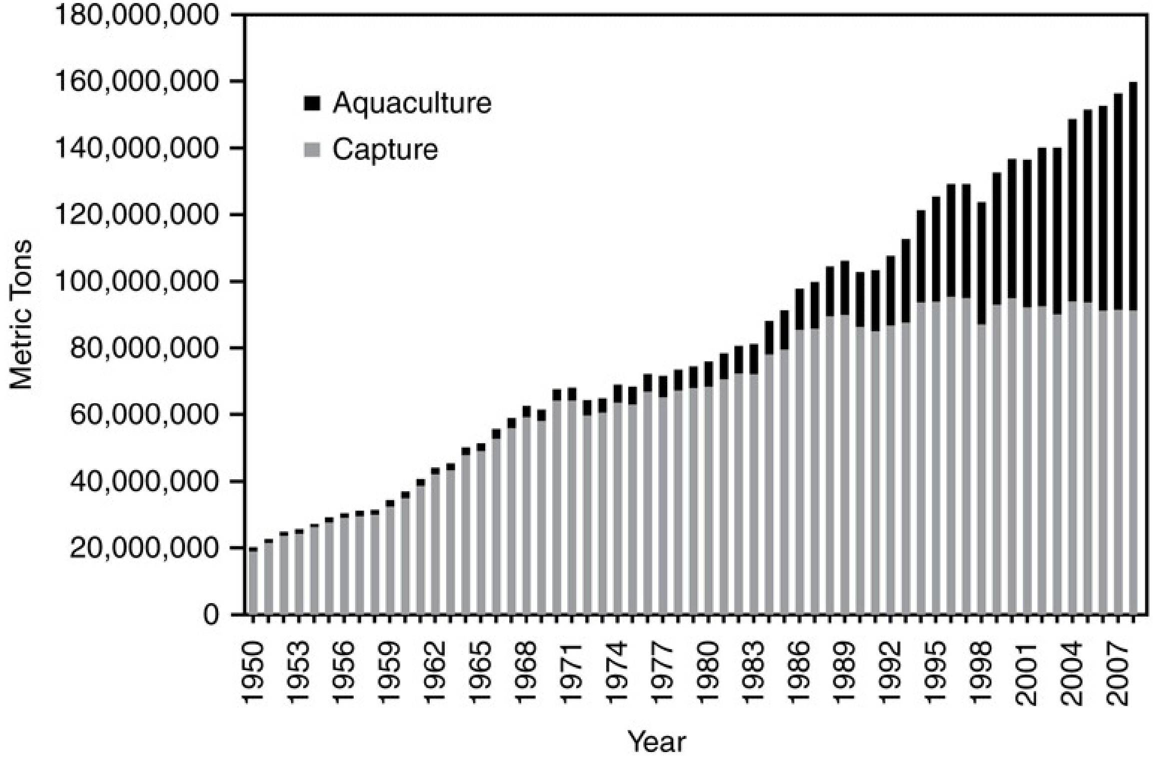
- Second, the phase-plane diagram explicitly shows the steady-state solution. As noted above this lies at the intersection of the two straight lines.
  - The horizontal line is a locus of all economic equilibrium points at which profit per boat is zero, and so effort is unchanging ($dE/dt = 0$).
  - The downward sloping straight line is a locus of all biological equilibrium points at which $G = H$, and so stock is unchanging ($dS/dt = 0$). Clearly, a bioeconomic equilibrium occurs at their intersection.

Public Policy Toward Fisheries

Aquaculture

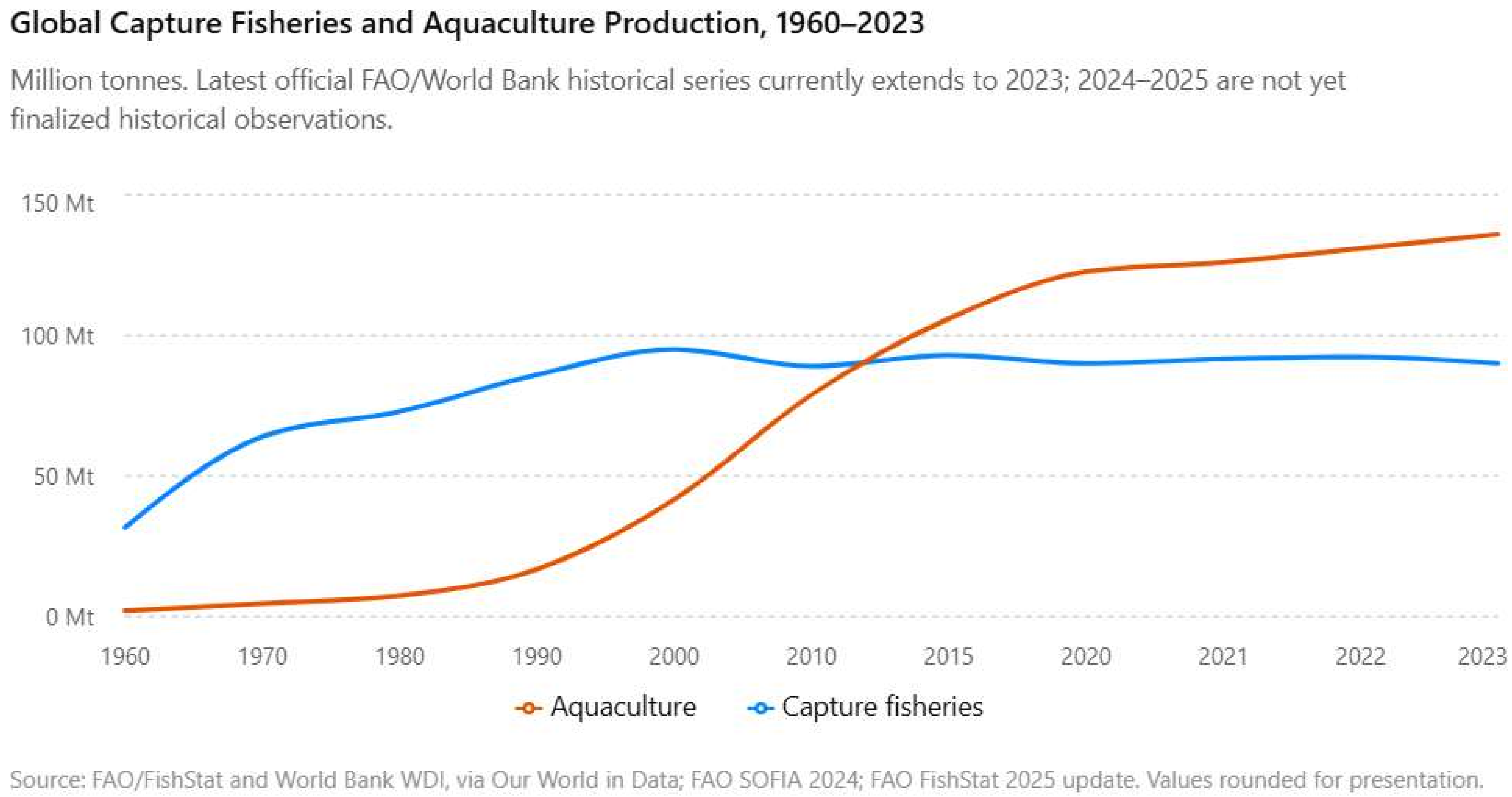
- Aquaculture is the controlled raising and harvesting of fish.
  - Fish farming involves cultivating fish over their lifetime.
  - Fish ranching involves holding fish in captivity for the first few years of their lives.

Global Capture and Aquaculture Production



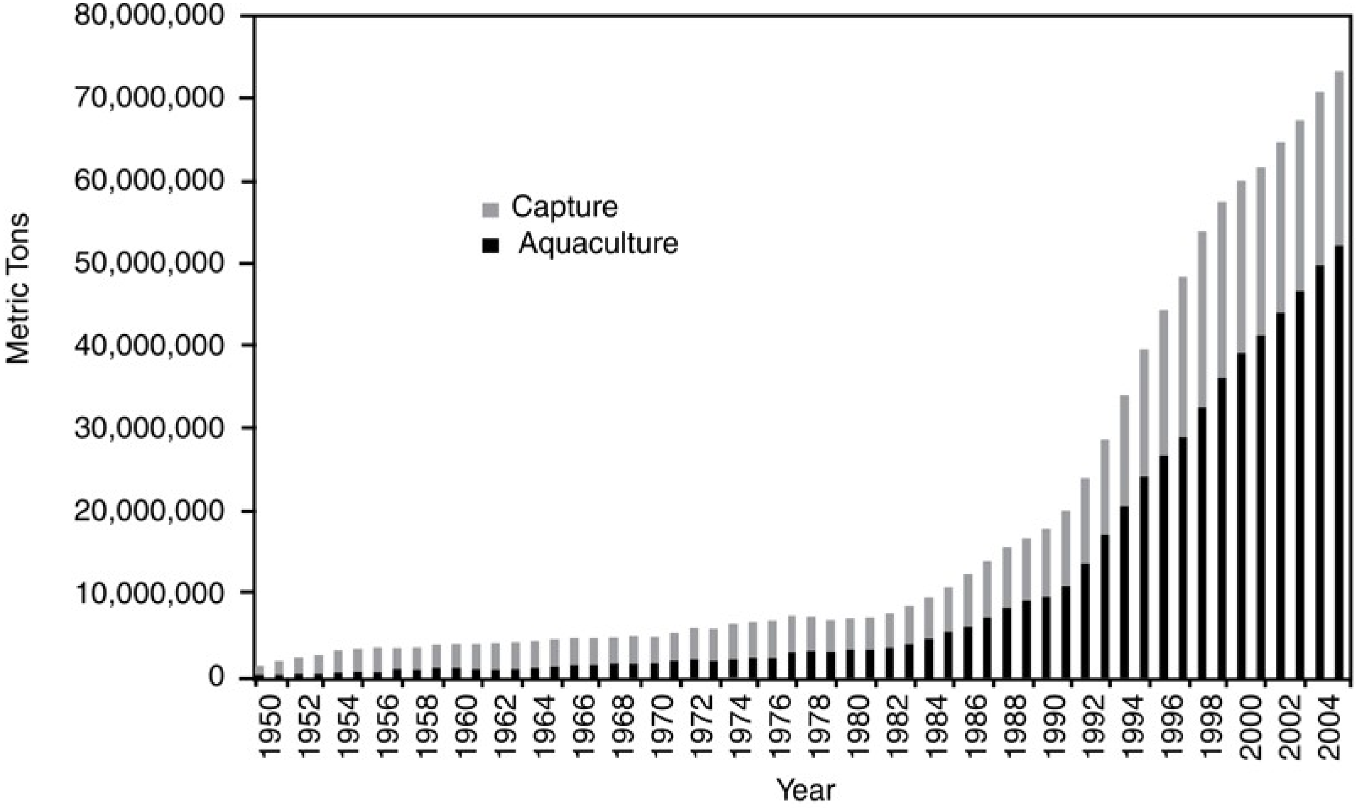
Source: "Global Capture and Aquaculture Production" from FISHSTAT PLUS Universal Software for Fishery Statistical Time Series, Version 2.3 (2000). Copyright © by Food and Agriculture Organization of the United Nations. Statistics and Information Services of the Fisheries and Aquaculture Department. Available at: http://www.fao.org/fishery/statistics/software/fishstat Reprinted with permission.

Global Capture and Aquaculture Production



Main message: capture fisheries rose rapidly until the late 1980s/early 1990s and then largely stabilized around **90 million tonnes** annually, while aquaculture expanded dramatically from about **2 million tonnes in 1960** to roughly **136 million tonnes in 2023**. FAO reported that total fisheries and aquaculture production reached **223.2 million tonnes in 2022**, with **130.9 million tonnes from aquaculture** and **92.3 million tonnes from capture fisheries**.

Chinese Capture and Aquaculture Production



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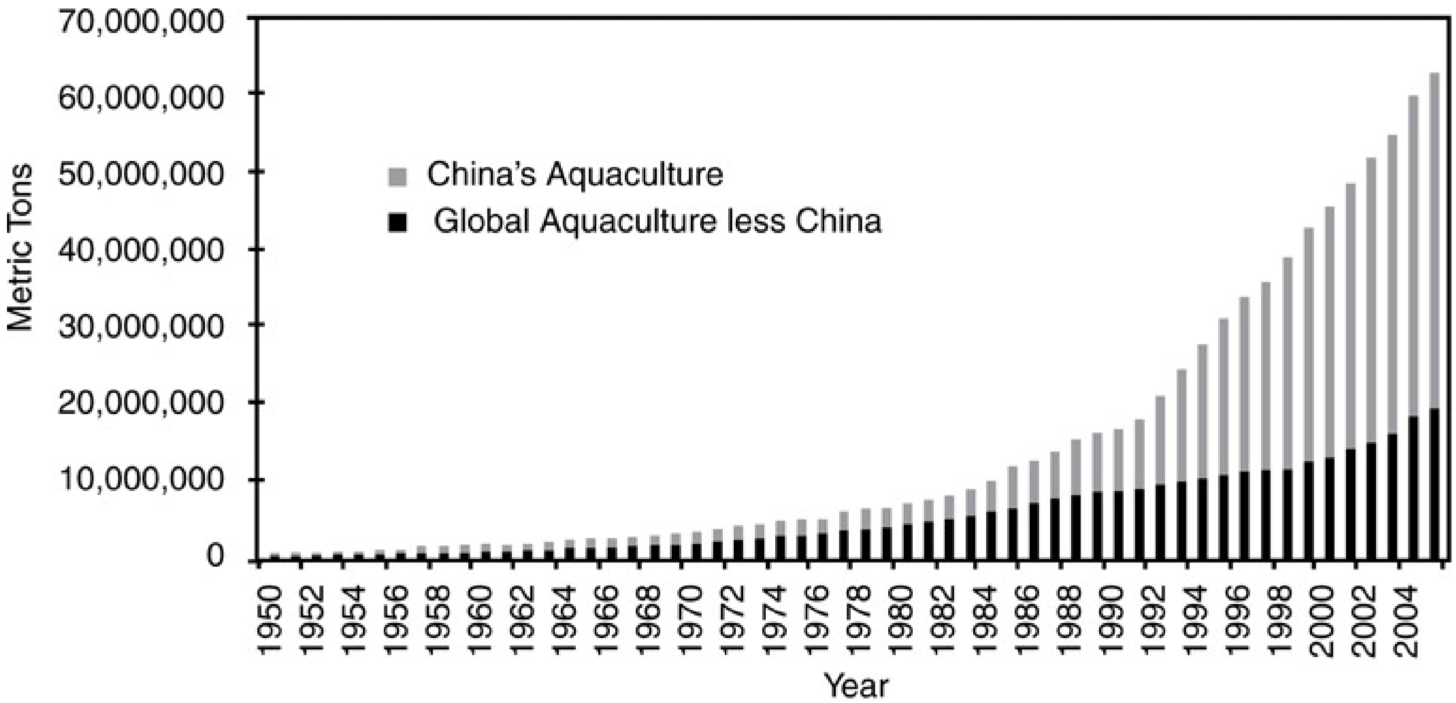
China's Rising Share of Aquaculture



Source: "China's Rising Share of Global Aquaculture" from FISHSTAT PLUS Universal Software for Fishery Statistical Time Series, Version 2.3 (2000). Copyright © by Food and Agriculture Organization of the United Nations. Statistics and Information Services of the Fisheries and Aquaculture Department. Available at: http://www.fao.org/fishery/statistics/software/fishstat Reprinted with permission.

DEBATE 13.1 Aquaculture: Does Privatization Cause More Problems than It Solves?

Privatization of commercial fisheries, namely through fish farming, has been touted as a solution to the overfishing problem. For certain species, it has been a great success. Some shellfish, for example, are easily managed and farmed through commercial aquaculture. For other species, however, the answer is not so clear-cut.

Atlantic salmon is a struggling species in the northeastern United States and for several rivers is listed as "endangered." Salmon farming takes the pressure off of the wild stocks. Atlantic salmon are intensively farmed off the coast of Maine, in northeastern Canada, in Norway, and in Chile. Farmed Atlantic salmon make up almost all of the farmed salmon market, and more than half of the total global salmon market. While farmed salmon offer a good alternative to wild salmon and aquaculture has helped meet the demand for salmon from consumers, it is not problem-free.

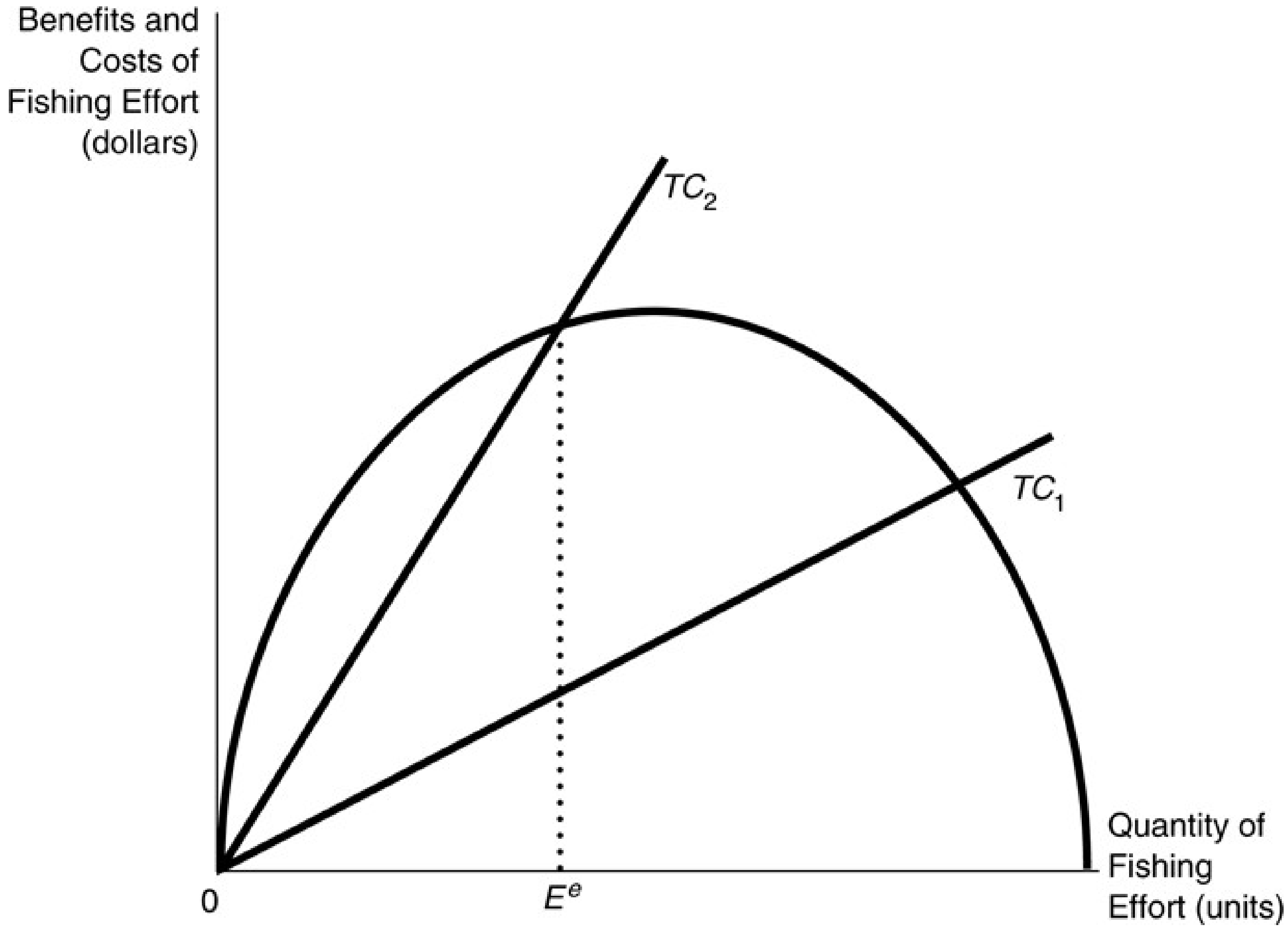
Escapees from the pens threaten native species, pollution that leaks from the pens creates a large externality, and pens that are visible from the coastline degrade the view of coastal residents. The crowded pens also facilitate the prevalence and diffusion of several diseases and illnesses, such as sea lice and salmon anemia. Antibiotics used to keep the fish healthy are considered dangerous for humans. Diseases in the pens can also be transferred to wild stocks. In 2007, the Atlantic Salmon Federation and 33 other conservation groups called on salmon farms to move their pens farther away from sensitive wild stocks.

Public Policy Toward Fisheries

Raising the real cost of fishing

- Raising the marginal cost of effort results in a lower harvest and higher stock sizes.
- While the policies may result in an efficient catch, they are inefficient because the efficient level of catch is not caught at the lowest possible cost.
- Technological innovations have lowered the cost of fishing, offsetting the increases imposed by regulations.

Effect of Regulation



Public Policy Toward Fisheries

Taxes

- Unlike regulations, the tax can lead to the static-efficient sustainable yield allocation because the tax revenues represent **transfer costs** and not **real-resource costs**.
- Transfer costs involve the transfer of resources from one part of society to another.
- For the individual fisherman, however, a tax still represents an increase in costs.

Public Policy Toward Fisheries

Individual Transferable Quotas (ITQs) and Catch Shares

- An efficient quota system will have the following characteristics:
  - The quotas entitle the holder to catch a specified volume of a specified type of fish.
  - The total amount of fish authorized by the quotas should be equal to the efficient catch level for that fishery.
  - The quotas should be freely transferable among fishermen.

Countries with Individual Transferable Quota Systems

Country	Number of Species Covered
Argentina	1
Australia	26
Canada	52
Chile	9
Denmark	1
Estonia	2
Falkland Islands	4
Greenland	1
Iceland	25
Italy	1
Morocco	1*
Mozambique	4
Namibia	10
The Netherlands	7
New Zealand	97
Portugal	1*
South Africa	1*
United States	6

*Complete species list unavailable

Source: Adapted from Cindy Chu. "Thirty Years Later: The Global Growth of ITQs and their Influence on Stock Status in Marine Fisheries," *Fish and Fisheries* Vol. 10 (2009): 217–230.

Public Policy Toward Fisheries

Subsidies and Buy Backs

- One of management options to reduce overcapacity.
  - Payments used to buy out excess fishing capacity are useful subsidies, but if additional capacity seeps in over time, they are not as effective as other management measures.

Public Policy Toward Fisheries

Marine protected areas and marine reserves

- Areas that prohibit harvesting and are protected from other threats such as pollution
  - Marine protected areas are designated ocean areas within which human activity is restricted.
  - Marine reserves protect individual species by preventing harvests within the reserve boundaries.

Public Policy Toward Fisheries

The 200-Mile Limit

- The 200-Mile Exclusion Zone is an international policy solution that has been implemented.
  - Countries bordering the sea now have ownership rights that extend 200 miles offshore. Within the 200-mile limit, the countries have exclusive jurisdiction.
  - This ruling protects coastal fisheries, but not the open ocean.

Public Policy Toward Fisheries

The Economics of Enforcement

- Implications for enforcement policies
  - To make compliance as inexpensive as possible
  - Regulations on noncompliance: sanctions
  - Enforcement cost and efficient population
  - Enforcement cost is affected by policy design.

Public Policy Toward Fisheries

Preventing Poaching

- Poaching (illegal harvesting) can introduce unsustainability.
- Poaching can be discourage if
  - Raising the relative cost of illegal activity
  - Economic incentive to local community
  - Transition from hunting to compensation

DEBATE 13.2 Bluefin Tuna: Is Its High Price Part of the Problem or Part of the Solution?

The population of bluefin tuna has plummeted 85 percent since 1970, with 60 percent of that loss occurring in the last decade. Japan is the largest consumer of bluefin tuna, which is prized for sushi. Fleets from Spain, Italy, and France are the primary suppliers. A single large bluefin can fetch $100,000 in a Tokyo fish market.

The International Commission for the Conservation of the Atlantic Tuna (ICCAT) is responsible for the conservation of highly migratory species, including several species of tuna. ICCAT reports fish biomass as well as catch statistics and is responsible for setting total allowable catch by species each year.

Since ICCAT has never successfully enforced their quotas, it is not clear that they have a credible enforcement capability. Monitoring statistics consistently show catch well above the TAC.

Additionally, international pressure from the fishing industry frequently results in a TAC higher than scientists recommend. In 2009, for example, having reviewed the current biomass statistics which showed the current stock to be at less than 15 percent of its original stock, ICCAT scientists recommended a total suspension of fishing. Ignoring their scientists' recommendation, ICCAT proceeded to set a quota of 13,500 tons. They did, however, also agree to establish new management measures for future years that will allow the stock to rebuild with an estimated 60 percent degree of confidence. While that sounds good, it turns out that if enforcement is less than perfect, and the resulting catch is above 13,500, the probability that the stock will recover cannot reach the 60 percent level by 2022 (Table 13.2).

DEBATE 13.2 Bluefin Tuna: Is Its High Price Part of the Problem or Part of the Solution?

TABLE 13.2 Probabilities of Stock Rebuilding at SSBF0.1 by Years and TAC Levels.

	Percent				
TAC	2010	2013	2016	2019	2022
0	0	2	25	69	99
2,000	0	1	21	62	99
4,000	0	1	18	55	99
6,000	0	1	14	47	97
8,000	0	0	11	40	92
10,000	0	0	9	33	84
12,000	0	0	6	26	73
13,500	0	0	5	21	63
14,000	0	0	4	20	59
16,000	0	0	3	14	46
18,000	0	0	2	10	34
20,000	0	0	1	6	24

Note: Grey color highlights the catch at which the 60 percent probability would not be achieved.

Source: REPORT OF THE 2010 ATLANTIC BLUEFIN TUNA STOCK ASSESSMENT SESSION (Table 1); ICCAT, www.iccat.int/en.

DEBATE 13.2 Bluefin Tuna: Is Its High Price Part of the Problem or Part of the Solution?

A rather different approach to protect the species was also tried in another forum. In 2009, a petition to ban trade in the Atlantic bluefin tuna went before the U.N. Convention on International Trade in Endangered Species (CITES). This was the first time that a major commercial fishery has been addressed by CITES. While conservationists and biologists supported the CITES listing, many industry groups were opposed. The National Fisheries Institute President, John Connelly, wrote in opposition, "Commercially-exploited aquatic species are fundamentally different from the other species that CITES regulates . . . Unlike these other species, fish and seafood stocks are not generally threatened with biological extinction. While they can and do become overfished, the resulting loss of return on investment for fishermen prevents them from driving commercial fish stocks toward biological extinction" (Gronewold, 2009). In early 2010, CITES voted against the ban. In January 2011, a record price was set for a northern bluefin. A giant 754-pound bluefin brought 32.5 million yen, or nearly $400,000. Do you think this price is a sufficient incentive to protect the bluefin tuna from extinction? Why or why not?

Sources: International Commission for the Conservation of Atlantic Tunas 2009 Annual ICCAT Meeting Press Release 16, November 2009; ICCAT, www.iccat.org; and Nathaniel Gronewold. "Is the Blue Fin Tuna an Endangered Species?" *Scientific American*, October 14, 2009, accessed online at http://www.scientificamerican.com/article.cfm?id=bluefin-tuna-stocks-threatened-cites-japan-monaco