Chapter 4

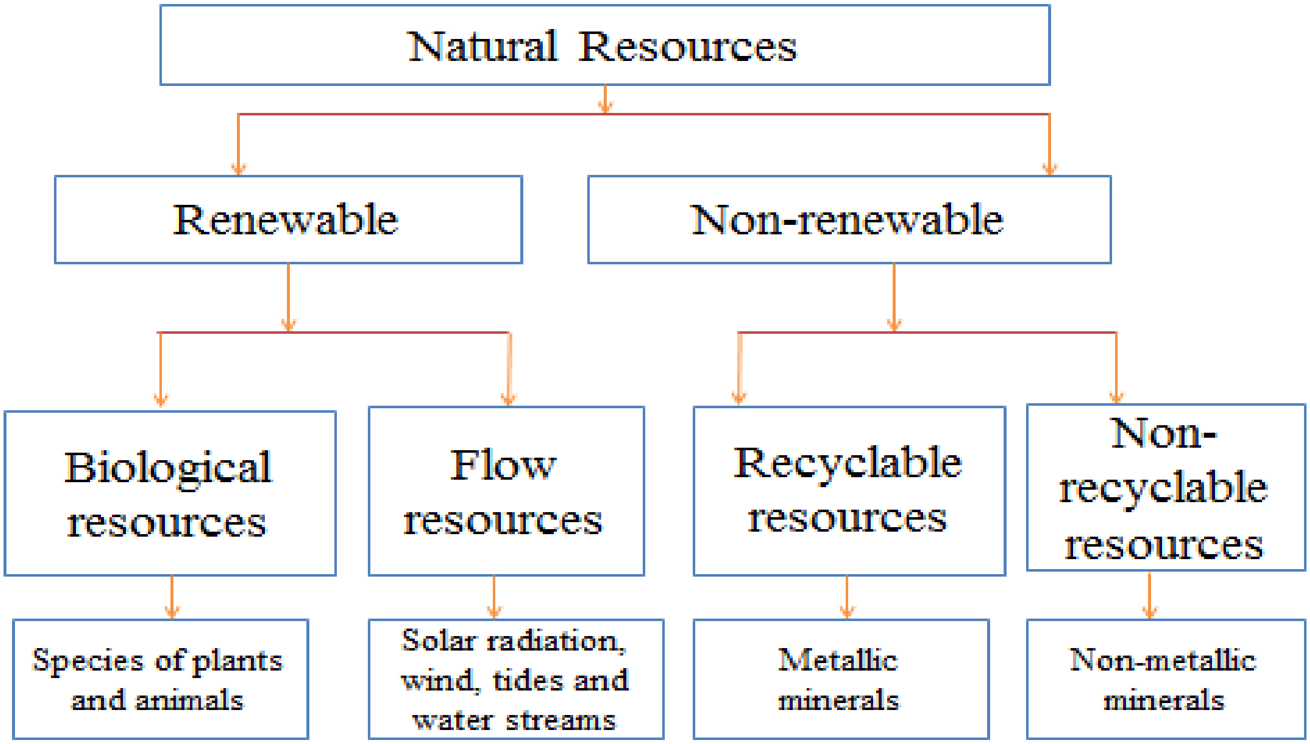
Natural Resources

- Broadly defined, natural resources include the Earth's natural endowments and the life-support systems (air, water, the Earth's crust, and radiation from the Sun).

Natural resources Vs. environmental resources

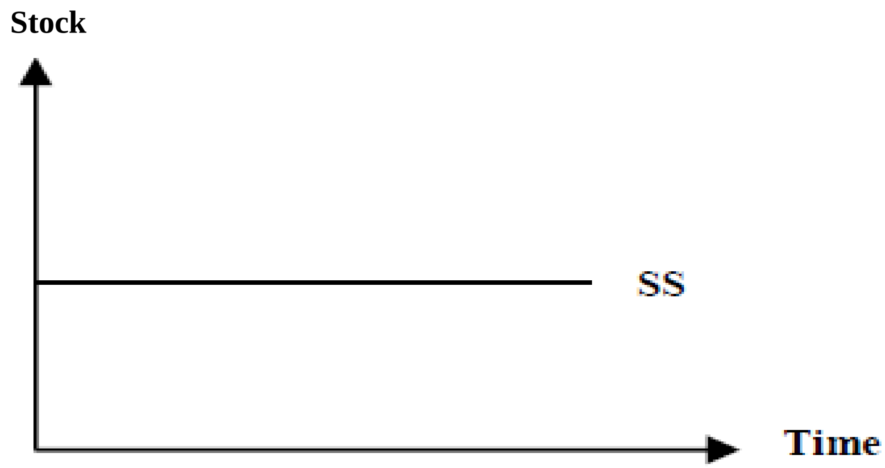
- Natural resources – resources provided by nature that can be divided into increasingly smaller units and allocated at the margin.
- Environmental resources – resources provided by nature that are indivisible.
- Natural resources serve as inputs to the economic system.
- Environmental resources are affected by the system (e.g. pollution).

4.1. Classification of Natural Resources



4.2. Non-renewable/Depletable/Exhaustible Natural Resources

- Non-renewable natural resources are resources that exist in a fixed supply (finite stock) for a long period of time.



- They are formed by geological processes over millions of years and exist as fixed stocks which, which once extracted, cannot be renewed.

☞ Their re-generative capacity can be assumed to be zero for all practical human purposes. Examples: metallic minerals like iron, aluminum, copper, and uranium; and non-metallic minerals like fossil fuels, clay, sand, salt, and phosphatase.

In general, a resource is said to be exhaustible if:

- its stock decreases over time when the resource is being used;
- its stock never increases over time;
- the rate of stock decrease is monotonically;
- no use is possible without a positive stock

4.1. Measurement of Stock of Depletable Resources and Resource Scarcity

Three separate concepts are used to classify the stock of depletable resources:

(1) current reserves
(2) potential reserves, and
(3) resource endowment

(1) Current reserves: is the total quantity (stock) of known resources that can profitably be extracted at current prices.

The magnitude of these current reserves can be expressed as a number. Q = 200mn tons of oil

- Part of a resource which cannot profitably exploited is not part of the current reserves.

(2) Potential Reserves: is the amount of resources potentially available.

- The amount of resources potentially available depends up on the price people are willing to pay for those resources.
    - The higher the price the larger the potential reserve
- They are most accurately defined as a function rather than a number. Q = f(P)

Example: the amount of additional oil that could be extracted from existing oil fields by enhanced extraction techniques

- As price increases, the amount of economically extractable oil also increases.

(3) Resource endowment: represents the natural occurrence of resources in the earth's crust.

- Since prices have nothing to do with the size of the resource endowment, it is a geological rather than an economic concept.
    - It represents an upper limit on the availability of terrestrial resources.

Possible Measures of Non-renewable Resource Scarcity

1. **Reserve- to-use ratio**

$$\text{RUR} = \frac{stock}{consumption}$$

- It is a physical indicator.
- If consumption is per year, this ratio indicates the time that is left until the resource is totally depleted.
- For instance, if the ratio is 30 it means that with the current consumption rate 30 years is left for the resource to be totally depleted.
- There is no economic concept in it.

2. Real resource price

- If the real price of the resource increases over time, it implies the resource becomes more and more scarce.
- Change in price of the resource over time is an indicator of the supply of that resource.
- Price also reflects the effect of different variables on the resource.
    - ✓ Existence and status of substitutes and complements
    - ✓ Technological progress
- Although price measures resource scarcity, it has some problems.
- Sometimes price may not reflect the true scarcity of the resource.
- This is true under the following situations:
    - ✓ *Price control* - leads to artificial prices so we could not use prices as a measure of scarcity.

- ✓ *Subsidy* - if government subsidizes a resource, price becomes low not because the resource is cheap but it is subsidized.

- Price is a good indicator of resource scarcity when we have competitive markets.

3. Marginal Extraction Cost (MEC)

- It is the additional cost of extracting a unit of resource.
- ➢ As the resource becomes more and more scarce, we will expect MEC to increase because as we extract more and more of non-renewable resource, we go deep to get some more resource which in turn increases cost of extraction.

4. Marginal Discovery Cost (MDC)

- It is the additional cost of discovering additional units of the resource.

5. Marginal Scarcity Rent (MSR)

- MSR= Price – Marginal Extraction Cost
- It can be used as an indicator of scarcity because price and MEC could tell us about scarcity of resource.
- We could expect MSR to increase as resource become more and more scarce.
- It is also called *royalty/marginal user cost/marginal net benefit of extraction*.

***4.2.* Theory of Optimal Depletion of Non-Renewable Natural Resources**

- Because allocation over time is the crucial issue, dynamic efficiency becomes the core concept.
- The dynamic efficiency criterion assumes that society's objective is to maximize the present value of net benefits coming from the resource.
- For a depletable, non-recyclable resource, this requires a balancing of the current and subsequent uses of the resource.

Non-Renewable Natural Resource Utilization under Different Scenarios

Efficient allocation of depletable resources depends on circumstances.

Case 1: Constant Marginal Extraction Cost with no Substitute Resource

In this scenario, we assume

- ➢ The depletable resource is extracted at constant marginal cost.
- ➢ Demand curve for the depletable resource is stable over time, and
- ➢ The depletable resource has no substitute.

i) The Two-Period Model Revisited

In the last chapter, we have developed the simple model of resource allocation over two periods. Recall the numerical example;

- √ Stable demand function for the depletable resource is $Pt = 8 - 0.4qt$

- √ Marginal extraction cost is $2.
- √ Fixed and finite supplies of the resource, $\overline{Q} = 20$
- √ No substitute resource is available
- √ $r = 0.1$
- √ The resource is allocated over two periods, $t = 1, 2$

The main remarks of the model are;

1. An efficient allocation results in more than half of the resource is allocated to the first period and less than half of it to the second period.
   - ➢ The efficient quantity of the depletable resource extracted declines over time.
2. The efficient allocation is affected by marginal cost of extraction and by the marginal user cost.
3. The marginal cost of extraction is assumed to be constant, but the value of the marginal user cost rises over time; why? Due to the fixed and finite supplies of depletable resources, production of a unit today precludes production of that unit tomorrow. Therefore, production decisions today must take forgone future net benefits into account. Marginal user cost is the opportunity cost measure that allows inter-temporal balancing to take place.
   - ➢ The rate of increase in the value of the marginal user cost is equal to r, the discount rate. That is, the marginal user cost rises at rate r in an efficient allocation in order to preserve the balance between present versus future production. $MUC_2 = (1 + r)MUC_1$
   - The condition that marginal user cost rises at rate r is true only when the marginal cost of extraction is constant

In summary, our two-period example suggests that an efficient allocation of a finite resource with a constant marginal cost of extraction involves rising marginal user cost and falling quantities consumed.

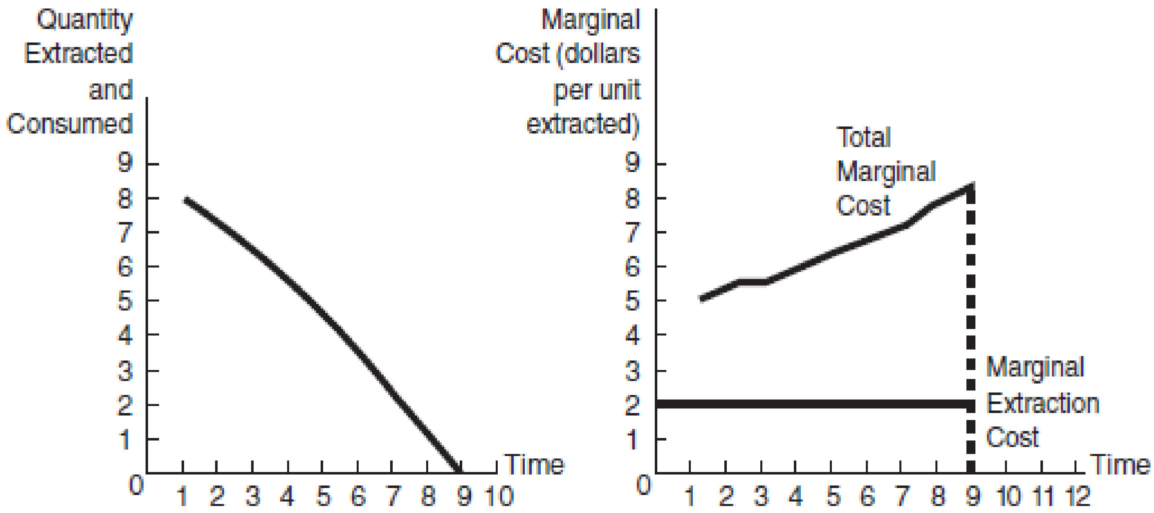
ii) The N-Period Model

This is the extension of the two-period model by extending the time horizon with which the resource is allocated. The two assumptions of the former model are retained.

The following generalizations can be made from the model.

1. In spite of the fact that marginal cost of extraction remains constant, the efficient marginal user cost rises steadily. This rise in the efficient marginal user cost reflects increasing scarcity and the accompanying rise in the opportunity cost of current consumption as the remaining stock falls.

2. In response to these rising costs over time, the extracted quantity falls over time until it finally goes to zero. At this point, total marginal cost is equal to the highest price anyone is willing to pay, so demand and supply simultaneously equal zero.



Case 2: Constant Marginal Extraction Cost with Substitute Resource

The substitute resource may be renewable resource or another depletable resource.

Thus, the transition to substitute could be from

√ Depletable to a renewable substitute resource

For example, from oil or natural gas to a solar substitute, from exhaustible groundwater to a surface-water substitute, etc.

√ Depletable to another depletable resource

i) Transition to a Renewable Substitute

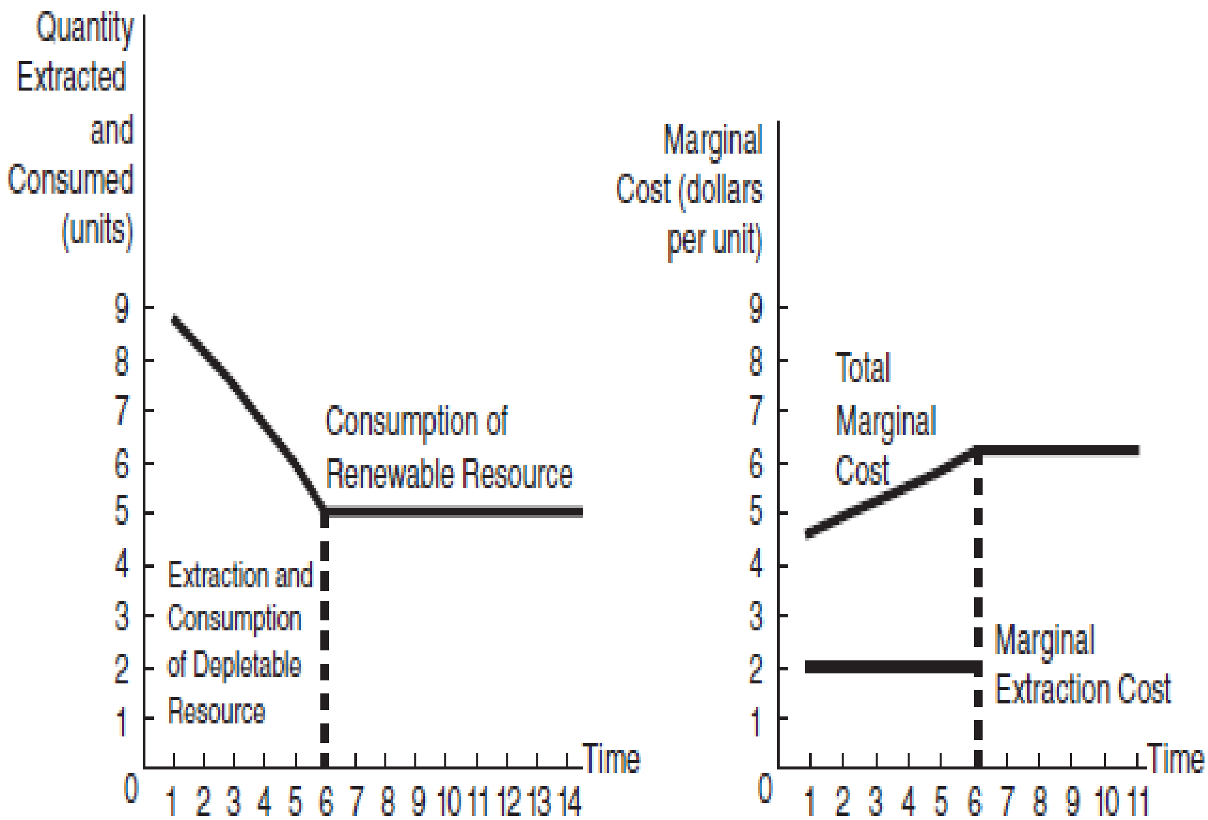
Suppose we consider the nature of an efficient allocation when a substitute renewable resource is available at constant marginal cost. How could we define an efficient allocation in this circumstance?

In this case, depletable resource would be exhausted just as it was in the previous case, but that will be less of a problem, since we will merely switch to the renewable one at the appropriate time. Suppose that a perfect renewable substitute for the depletable resource is infinitely available at a cost of $6 per unit.

☞ The transition from the depletable resource to this renewable resource would ultimately transpire because the renewable resource marginal cost ($6) is less than the maximum willingness to pay ($8).

☞ The total marginal cost for the depletable resource in the presence of a $6 perfect substitute would never exceed $6 because society could always use the renewable resource instead, whenever it was cheaper.

Thus, while the maximum willingness to pay (the *choke price*) sets the upper limit on total marginal cost when no substitute is available, the marginal cost of extraction of the substitute sets the upper limit when a perfect substitute is available at a marginal cost lower than the choke price.



Note the followings:

☞ In this efficient allocation, quantity extracted per unit of time is gradually reduced as the marginal user cost rises until the switch is made to the substitute.

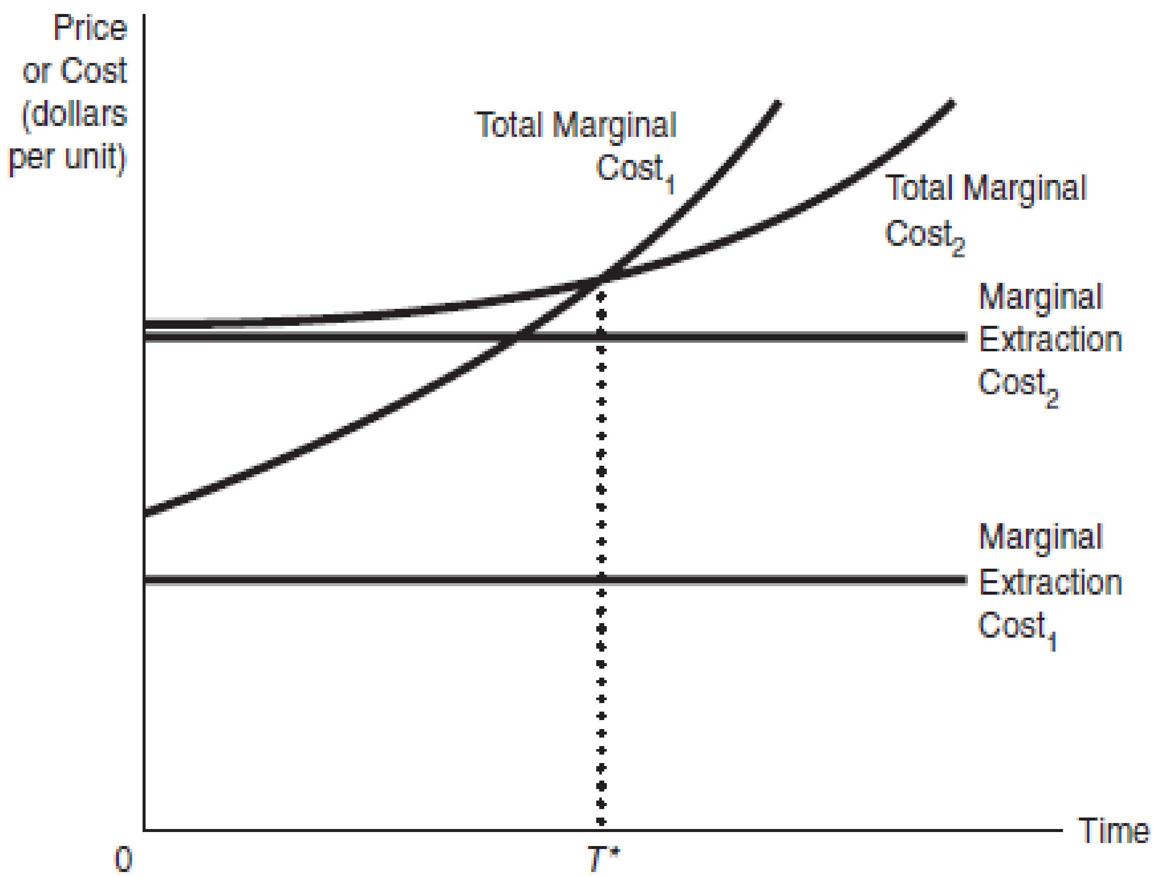
☞ Because the renewable resource is available, more of the depletable resource would be extracted in the earlier periods than it would have been without a renewable resource substitute. As a result, the depletable resource would be exhausted sooner than it would have been without the renewable resource substitute. When a substitute is available, the need to save some of the depletable resource for the future is certainly less pressing (in other words, the opportunity cost has fallen).

☞ At the transition point, called the switch point, consumption of the renewable resource begins. Prior to the switch point, only the depletable resource is consumed, while after the switch point only the renewable resource is consumed. This sequencing of consumption pattern results from the cost patterns. Prior to the switch point, the depletable resource is cheaper. At the switch point, the marginal cost of the depletable resource (including marginal user cost) rises to meet the marginal cost of the substitute, and the transition occurs.

Due to the availability of the substitute resource, after the switch point consumption never drops below five units in any time period. This level is maintained because five is the amount that maximizes the net benefit when the marginal cost equals $6 (the price of the substitute). (Substituting $6 into the willingness-to-pay function and solving for the quantity demanded.)

ii) The Transition from a Depletable Resource to another Depletable Resource

Assume that the transition is from one constant marginal-cost depletable resource to another depletable resource with a constant, but higher, marginal extraction cost. The total marginal cost of the first resource would rise over time until it equaled that of the second resource at the time of transition (T*). Before the transition, only the first resource is consumed (because it is cheaper) and unfortunately all of it would have been consumed by T*.



Total marginal cost path reveals the following characteristics:

1. The transition is a smooth one; total marginal cost never jumps to the higher level.

The total marginal costs of the two resources are equal only at the time of transition. If they weren't equal, the net benefit could be increased by switching to the lower-cost resource from the more expensive resource. Total marginal costs are not equal in the other periods. In the period before transition, the first resource is cheaper and therefore used exclusively, whereas after transition the first resource is exhausted, leaving only the second resource.

2. The slope of the total marginal cost curve over time is flatter after the time of transition.

This is because the component of total marginal cost that is growing (the marginal user cost) represents a smaller portion of the total marginal cost of the second resource than of the first.

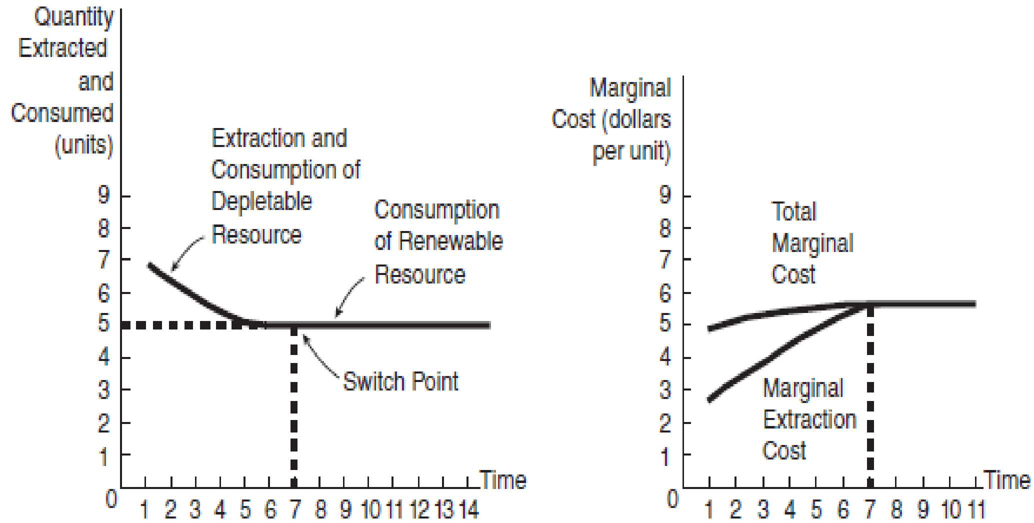
The total marginal cost of each resource is determined by the marginal extraction cost plus the marginal user cost. In both cases, the marginal user cost is increasing at rate r, and the marginal cost of extraction is constant. The marginal cost of extraction, which is constant, constitutes a much larger proportion of total marginal cost for the second resource than for the first. Hence, total marginal cost rises more slowly for the second resource, at least initially.

It should be noted that MUC is always positive for depletable resources because using these resources reduces the net benefits received by the future generation.=> MUC for non-depletable resources is zero.

Case 3: Increasing Marginal Extraction Cost with Substitute Resource

This a situation in which the marginal cost of extracting the depletable resource rises with the cumulative amount extracted. This is more realistic case, for example, with minerals, where the higher-grade ores are extracted first, followed by an increasing reliance on lower-grade ones.

The dynamic efficient allocation of this resource is found by maximizing the present value of the net benefits, using this modified cost of extraction function. However, the marginal cost of extraction increases with the cumulative amount extracted. For example, $MECt = \$2 + 0.1Qt$ where Qt is cumulative extraction to date.



Note the behavior of marginal user cost. In the previous case, we noted that marginal user cost rose over time at rate r. When the marginal cost of extraction increases with the cumulative amount extracted, marginal user cost declines over time until, at the time of transition to the renewable resource, it goes to zero. Why?

Remember that marginal user cost is an opportunity cost reflecting forgone future marginal net benefits. In contrast to the constant marginal extraction cost case, in the increasing marginal extraction cost case every unit extracted now raises the cost of future extraction. Therefore, as the current marginal extraction cost rises over time, the sacrifice made by future generations (as an additional unit is consumed earlier) diminishes; the net benefit that would be received by a future generation, if a unit of the resource were saved for them, gets smaller and smaller as the marginal extraction cost of that resource gets larger and larger. By the last period, the marginal extraction cost is so high that earlier consumption of one more unit imposes virtually no sacrifice at all. At the switch point, the opportunity cost of current extraction drops to zero, and total marginal cost equals the marginal extraction cost.

The increasing cost case differs from the constant cost case in another important way as well. In the constant cost case, the depletable resource reserve is ultimately completely exhausted. In the increasing cost case, however, the reserve is not exhausted; some is left in the ground because it is more expensive to use than the substitute.

Numerical Example: Ricardian Rents in a Dynamically Efficient Model of Nonrenewable Resource Extraction with Increasing Marginal Extraction Costs

In the two-period model price in each period is given by

$P_t = 11 - Q_t$, so total willingness-to pay, the area under the demand curve, is

$TWTP_t = \int_0^{Q_t} (11 - Q)dQ = 11Q_t - \frac{1}{2}Q_t^2$ with $t = 1,2$. Marginal extraction cost in the first period is $MEC_1 = Q_1$, and marginal extraction cost in the second period is $MEC_2 = Q_1 + Q_2$. Consequently, total extraction cost in the first period is $TEC_1 = \int_0^{Q_1} (Q)dQ = \frac{1}{2}Q_1^2$, and total extraction cost in the second period is

$TEC_2 = \int_0^{Q_2} (Q_1 + Q)dQ = Q_1Q_2 + \frac{1}{2}Q_2^2$. Therefore, total net benefits in period 1 are

$TNB_1 = TWTP_1 - TEC_1 = 11Q_1 - \frac{1}{2}Q_1^2 - \frac{1}{2}Q_1^2 = 11Q_1 - Q_1^2$, and total net benefits in period 2 are $TNB_2 = TWTP_2 - TEC_2 = 11Q_2 - \frac{1}{2}Q_2^2 - Q_1Q_2 - \frac{1}{2}Q_2^2 = 11Q_2 - Q_1Q_2 - Q_2^2$. The initial resource stock is $\overline{Q} = 10$ and the real discount rate is $r = 0.50$. Dynamic efficiency is synonymous with maximizing the present value sum of economic net benefits over the two periods:

$$\max_{Q_1, Q_2} V = TNB_1 + \frac{TNB_2}{1.5} = [11Q_1 - Q_1^2] + \frac{[11Q_2 - Q_1Q_2 - Q_2^2]}{1.5}.$$

The two first-order necessary conditions for maximization are

$\frac{\partial V}{\partial Q_1} = 11 - 2Q_1 - \frac{Q_2}{1.5} = 0$ and $\frac{\partial V}{\partial Q_2} = \frac{11 - Q_1 - 2Q_2}{1.5} = 0$. Solving these two equations simultaneously yields

$Q_1^* = 4.4$, $P_1^* = 11 - 4.4 = \$6.6$, $MEC_1 = \$4.4$, $Q_2^* = 3.3$, $P_2^* = 11 - 3.3 = \$7.7$, and $MEC_2 = 4.4 + 3.3 = \$7.7$. The marginal net benefit of extraction in period 1 (the Ricardian rent in period 1) is $MNB_1 = P_1 - MEC_1 = 6.6 - 4.4 = \$2.2$. The present value increase in costs in period 2 from marginal extraction in period 1 is $\frac{Q_2^*}{1.5} = \frac{3.3}{1.5} = \$2.2$ because the last unit extracted in period 1 increases the cost of extraction of every unit produced in period 2 by \$1. The Ricardian rent in period 2 is zero because price equals marginal cost. Of the 10 units in the initial resource stock, 2.3 units $(= 10 - Q_1^* - Q_2^* = 10 - 7.7)$ remain in the ground and are not extracted by the end of period 2.

Exploration and Technological Progress

The models considered to this point have not yet included a consideration of the role the exploration for new resources or technological progress—historically significant factors in the determination of actual consumption paths.

The search for new resources is expensive. As easily discovered resources are exhausted, searches are initiated in less rewarding environments, such as the bottom of the ocean or locations deep within the earth. This suggests the marginal cost of exploration, which is the marginal cost of finding additional units of the resource, should be expected to rise over time, just as the marginal cost of extraction does.

As the total marginal cost for a resource rises over time, society should actively explore possible new sources of that resource. Larger increases in the marginal cost of extraction for known sources trigger larger potential increases in net benefits from finding new sources.

If the marginal extraction cost of the newly discovered resources is low enough, these discoveries could lower, or at least delay, the increase in the total marginal cost of production. As a result, the new finds would tend to encourage more consumption. Compared to a situation with no exploration possible, the model with exploration would show a smaller and slower decline in consumption, while the rise in total marginal cost would be reduced.

It is also not difficult to expand our concept of efficient resource allocations to include technological progress, the general term economists give to advances in the state of knowledge. Technological progress reduces the cost of extraction overtime. Thus, introducing technological progress and exploration activity into the model tends to delay the transition to renewable resources. Exploration expands the size of current reserves, while technological progress keeps marginal extraction cost from rising. If these effects are sufficiently potent, marginal cost could actually decline for some period of time, causing the quantity extracted to rise.

4.3 Renewable Resources

Renewable Resources are those resources useful to human economies that exhibit growth, maintenance and recovery from exploitation over an economic planning horizon. They have the capacity to grow and reproduced.

Examples: Fish, forests, water (surface or groundwater) and energy resources, such as wind and solar radiation.

Typical economic question in the management of renewable natural resources are;

- ✓ How much of a resource should be harvested during the present vs. future time periods?
- ✓ Fishery: How much to harvest this season and how much to leave in the sea as a source for future growth next season harvest?
- ✓ Forestry: What is the optimal length of time between harvests that maximizes a forest owner's profits?

4.3.1 Fisheries

A fishery is an area where fish are caught-a fishing ground-or a firm in the fishing business.

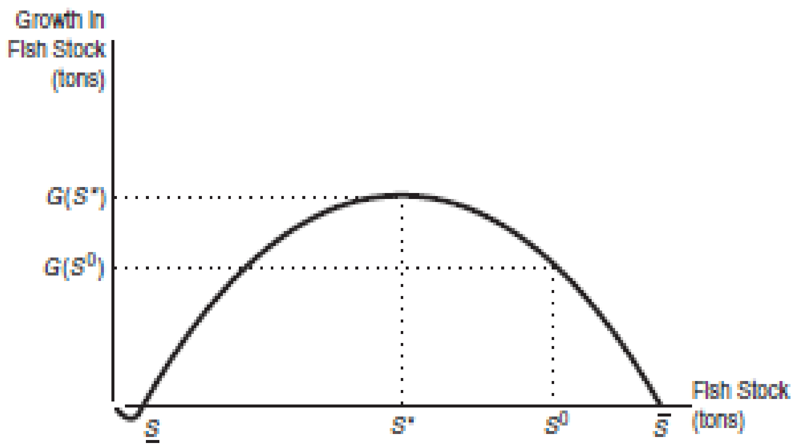
The size of fish depends on both biological factor (reproductivity) and human action (level of utilization of the fish), i.e., fishing reduces the stock of fish, which in turn reduce the rate of natural increase of the fish population.

Biological Dimension of Fisheries

The biological characterization of the fishery rests on a model initially proposed by Schaefer (1957). Schaefer model points a particular average relationship between the growth of the fish population and the size of the fish population.

The size of the population is represented on the horizontal axis and the growth of the population on the vertical axis.

Fig: Relationship between the Fish Population (Stock) and Growth



- The graph suggests that there is a range of population sizes ($\underline{S} - S^*$) where population growth increases as the population increases and a range ($S^* - \overline{S}$) where initial increases in population lead to eventual declines in growth.
- At two points ($\underline{S}$ and $\overline{S}$) the function intersects the horizontal axis which means growth in the stock is zero.
- $\overline{S}$ is known as the *natural equilibrium*, since it is population size that would persist in the absence of outside influences. Reductions in the stock due to mortality or out-migration would be exactly offset by increases in the stock due to births, growth of the fish in the remaining stock, and in-migration. This natural equilibrium would persist because it is *stable*. A stable equilibrium is one in which movements away from this population level set force in motion to restore it.
  - If the stock exceeds $\overline{S}$, it is exceeding the capacity of its habitat (called carrying capacity). As a result, mortality rates or out-migration will increase until the stock is once again within the confines of the carrying capacity of its habitat at $\overline{S}$.
  - If the stock is less than $\overline{S}$, the stock will be smaller, and hence growth will be positive and the size of the stock will increase. Over time, the fishery will move along the curve to the right until $\overline{S}$ is reached again.
- $\underline{S}$ is known as the *minimum viable population*, which represents the level of population below which growth in population is negative (deaths and out-migration excee births and in-migration).
  - In contrast to $\overline{S}$, $\underline{S}$ is unstable equilibrium. Population sizes above $\underline{S}$ lead to positive growth and a movement away from $\underline{S}$ along the curve to $\overline{S}$. When the population moves to the left

of $\underline{S}$, the population declines until it eventually becomes extinct. In this region, no forces act to return the population to a viable level.

- 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. As long as the population size remains constant, the growth rate (and hence the catch) will remain constant as well. The sustainable yield for any population size (between $\underline{S}$ and $\overline{S}$) can be determined by drawing a vertical line from the stock size of interest on the horizontal axis to the point at which it intersects the growth function, and drawing a horizontal line over to the vertical axis. The sustainable yield is the growth in the biomass defined by the intersection of this horizontal line with the vertical axis. For example, G(S^0) is the sustainable yield for population size S^0. Since the catch is equal to the growth, population size (and next year's growth) remains the same.
- S* is known in biology as the *maximum sustainable yield population*, 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. G(S*) is the maximum sustainable yield. Larger catches would be possible in the short run, but these could not be sustained; they would lead to reduced population sizes and eventually, if the population were drawn down to a level smaller than , to the extinction of the species.

Static Efficient Sustainable Yield

Is the maximum sustainable yield synonymous with efficiency? The answer is no.

Recall that efficiency is associated with maximizing the net benefit from the use of the resource. If we are to define the efficient allocation, we must include the costs of harvesting as well as the benefits.

Let's begin by defining the efficient sustainable yield without worrying about discounting. The static efficient sustainable yield is the catch level that, if maintained perpetually, would produce the largest annual net benefit. We shall refer to this as the static efficient sustainable yield to distinguish it from the dynamic efficient sustainable yield, which incorporates discounting.

To simplify the analysis, let us assume that

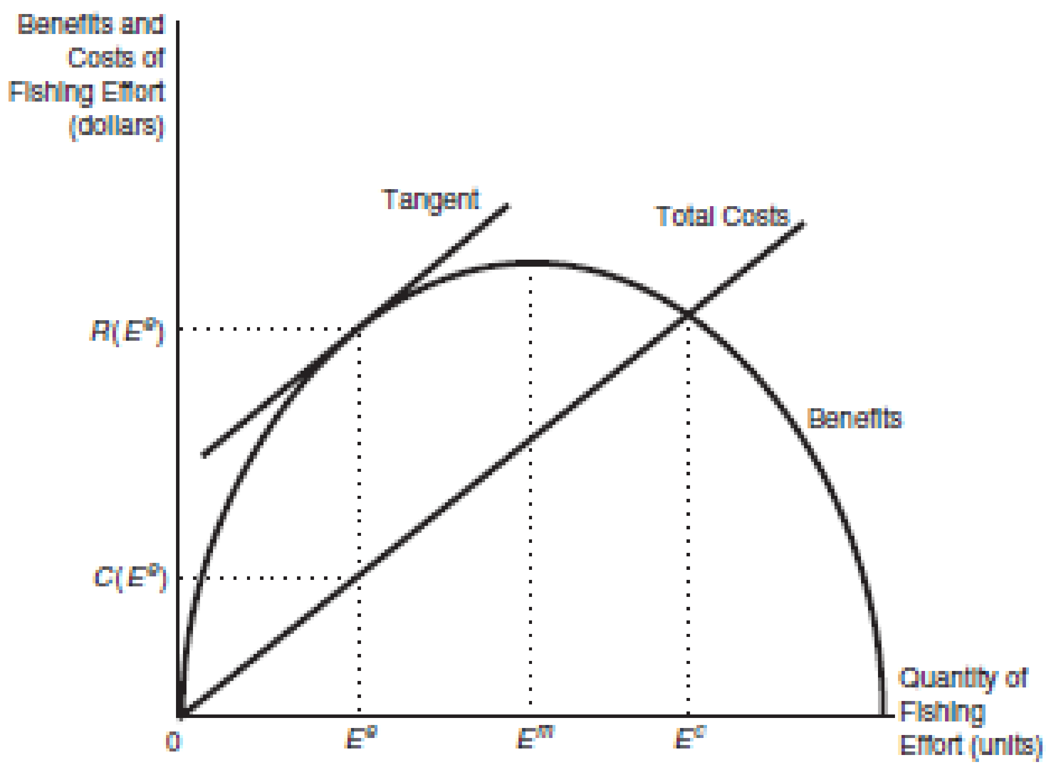
(1) the price of fish is constant and does not depend on the amount sold;

(2) the marginal cost of a unit of fishing effort is constant; and

(3) the amount of fish caught per unit of effort expended is proportional to the size of fish population (the smaller the population, the fewer fish caught per unit of effort).

- In any sustainable yield, annual catches, population, effort levels, and net benefits, by definition, remain constant over time. The static efficient sustainable yield allocation maximizes the constant annual net benefit.
- The benefits (revenues) and costs are shown as a function of fishing effort which can be measured in vessel years, hours of fishing, or some other convenient metric.
- 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 would result in smaller population sizes and would be measured as a movement from right to left. That is, the population size is a negatively sloped function of the level of effort.
- The maximum population size (involving zero effort) is equal to the carrying capacity, while the minimum population size is zero. Because the variable on the horizontal axis is effort, and not population, an increase in fishing effort is measured as a movement from left to right.

Fig: Efficient Sustainable Yield for a Fishery



As sustained levels of effort are increased, eventually a point is reached (E^m) at which further effort reduces the sustainable catch and revenue for all years. Point E^m corresponds to the maximum sustainable yield, G(S*).

The net benefit is presented in the diagram as the difference (vertical distance) between benefits (prices times the quantity caught) and costs (the constant marginal cost of effort times the units of effort expended). The efficient level of effort is E^e is the point at which the vertical distance between benefits and costs is maximized.

E^e is the efficient level of effort because it is where marginal benefit (which graphically is the slope of the total benefit curve) is equal to marginal cost (the constant slope of the total cost curve). Levels of effort higher than E^e are inefficient because the additional cost associated with them exceeds the additional benefit of the fish obtained. Can you see why lower levels of effort are also inefficient?

Is the maximum sustainable yield efficient? The answer is clearly no. The maximum sustainable yield would be efficient only if the marginal cost of additional effort were zero. Can you see why? What is the marginal benefit at the maximum sustainable yield? Since at E^m the marginal benefit is lower than marginal cost, the efficient level of effort is less than that necessary to harvest the maximum sustainable yield. Thus, the static efficient level of effort leads to *a larger* fish population, but a lower annual catch than the maximum sustainable yield level of effort.

Now, let us consider what would happen to the static efficient sustainable yield if a technological change were to occur, lowering the marginal cost of fishing. The lower marginal cost would result in a rotation of the total cost curve to the right. With this new cost structure, the old level of effort would no longer be efficient. The marginal cost of fishing (slope of the total cost curve) would now be lower than the marginal benefit (slope of the total benefit curve). Since the marginal cost is constant, the equality of marginal cost and marginal benefit can result only from a decline in marginal benefits. This implies an increase in effort. The new static efficient sustainable yield equilibrium implies more annual effort, a lower population level, a larger annual catch, and a higher net benefit for the fishery.

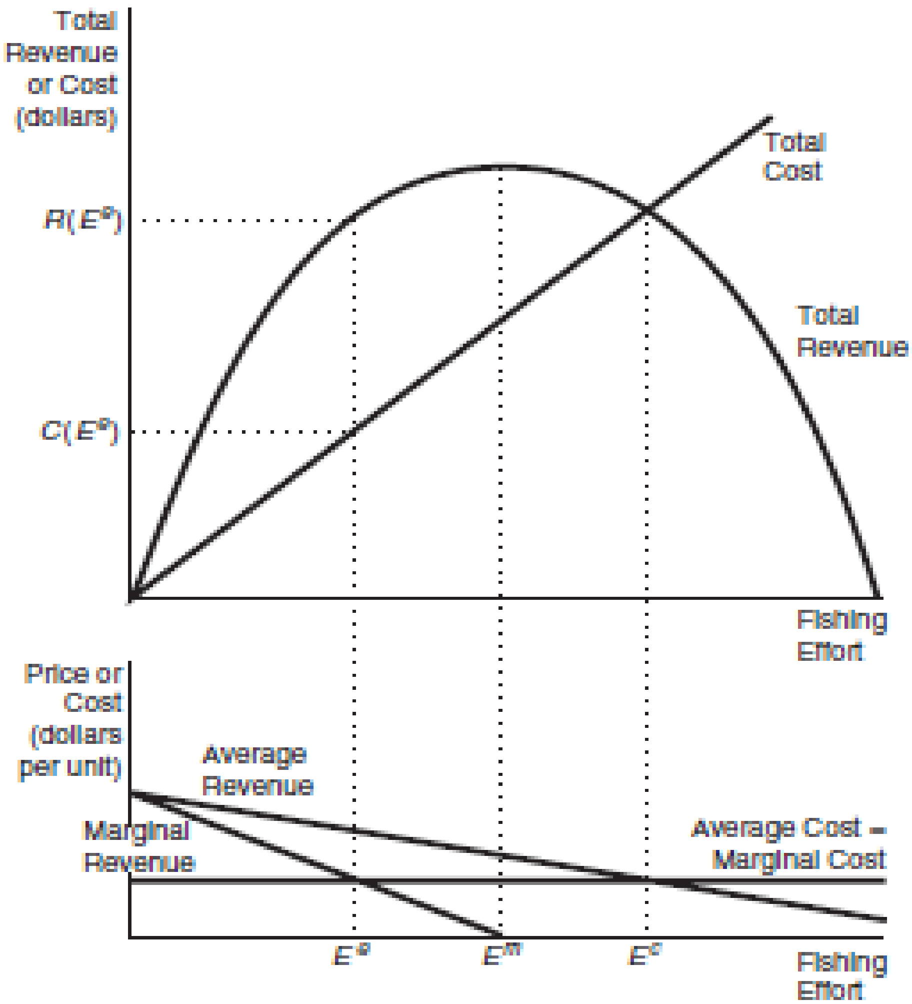
Private Fishing vs. Open-Access Fishing

Let's first consider the allocation resulting from a fishery managed by a competitive sole owner. A sole owner would have a well-defined property right to the fish.

A sole owner would want to maximize his or her profits. Ignoring discounting for the moment, the owner can increase profits by increasing 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).

In ocean fisheries, however, sole owners are unlikely. Ocean fisheries are typically open-access resources--no one exercises complete control over them. Since the property rights to the fishery are not conveyed to any single owner, no fisherman can exclude others from exploiting the fishery.

Fig: Market Allocation in a Fishery



What problems arise when access to the fishery is completely unrestricted?

Open-access resources create two kinds of external costs: a contemporaneous external cost and an intergenerational external cost. The contemporaneous external cost, which is borne by the current generation, involves the over-commitment of resources to fishing---too many boats, too many fishermen, too much effort. As a result, current fishermen earn a substantially lower rate of return on their efforts.

The intergenerational external cost, borne by future generations, occurs because over-fishing reduces the stock, which, in turn, lowers future profits from fishing.

Open-access fishing may or may not pose the threat of species extinction.

It depends on the nature of the species and the benefits and costs of an effort level above E^m that would have the effect of driving the stock level below the minimum viable population. Are open-access resources and common property resources synonymous concepts? They are not. Not all common property resources allow unlimited access. Informal arrangements among those harvesting the common property resource, for example, can serve to limit access.

Harvesting Decision: Fisheries

I. Biological Equilibrium Analysis of Fishery---Maximum Sustainable Yield

i. Growth Function

Defining the efficient sustainable yield for a fishery begins with a characterization of the biological relationship between the growth for the biomass and the size of the biomass.

The standard biological relationship is given by the logistic growth function.

$$\dot{X} = f[X(t)] = rX(t)(1 - \frac{X(t)}{k}) \text{ -- } (1)$$

where

$\dot{X} =$ the growth rate of the biomass without harvesting,

$r =$ the intrinsic growth rate for this species,

$X(t) =$ the size of the biomass (stock of the resource), and

$k =$ the carrying capacity of the habitat.

ii. Harvest/Yield Function

When a resource is harvested, it is assumed that the rate of harvest is a function of the economic inputs devoted to the harvesting and of the available stock.

$Y(t) \; = \; H[E(t), X(t)]$

where $Y(t) =$ the production function or rate of harvest (measured in the same unit as $X(t)$)

$X(t) =$ resource stock (such as forests fish, wild life, etc.)

$E(t) =$ effort, i.e., aggregate measure of various inputs (or economic inputs that we use for harvesting), for example, the number of vessel or days devoted to fishing during the particular year

A production function commonly used in fishing management is

$$Y(t) \; = \; qE(t).X(t) \text{ -- } (2)$$

where q is constant

Assumptions used in this function are;

- ✓ Catch per unit effort (Y/E) is directly proportional to the density of the fish in the sea.
- ✓ The density of the fish is directly proportional to the abundance $X(t)$.

Rate of Growth of Resource stock with Harvesting

With harvesting, the rate of growth (or change) in the resource stock must reflect

- the resource stock, $f(X(t))$

- the harvest, $Y(t)$

Thus, we have $\dot{X} = f[X(t)] - Y(t)$ -- (3)

This simply states that the growth rate of the resource,$\dot{X}$, is a function of the resource stock, $f(X(t))$, and the rate of harvest,$Y(t)$.

Note that without harvesting, equation (4) becomes imply $\dot{X} = f[X(t)]$

iii. Sustained Yield Function

By sustained yield function, we mean that X, Y, and E all remain constant over time. Therefore, the sustained yield function is an equilibrium concept expressing sustainable harvest (yield) as a function of effort.

Since X, Y, and E are constant, $\dot{X} = 0$

$\dot{X} = f(X) - Y = 0$ --- (4)

$Y = H[E, X]$

From (2), $Y = qEX$-- (5)

From (1), (4) and (5), we have $\dot{X} = rX\left(1 - \frac{X}{k}\right) - qEX = 0$

Solving for X yields;

$X = k(1 - \frac{qE}{r})$-- (6)

Finally, the sustained yield function will be;

$Y = qEk(1 - \frac{qE}{r})$--- (7)

This is the Schaefer-Fisheries model and is also called Yield-Effort Function. (It is the combination of logistic growth model and the yield function.)

In equation (7), qE is relative rate of harvest and r is intrinsic (natural) rate of growth of the fish stock.

Note that if $qE = r$, then $Y = 0$.

Interpretation of the above statement:

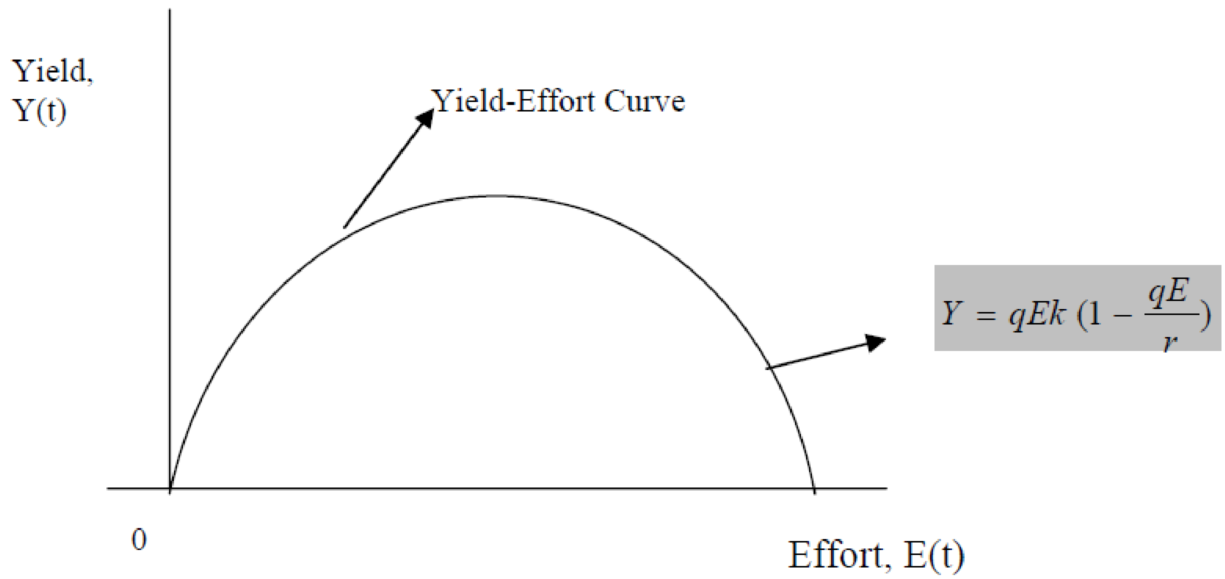
In equation (7), if the relative rate of harvest (qE) exceeds the rate of growth of the fish stock (r), then the population will be driven to extinction and the yield become zero.

The Yield -Effort Curve

The yield effort curve is a concave or bell-shaped curve that describes the amount of a given resource harvested in relation to effort.

It is proved that the yield rises, reaches a maximum and then begins to decline as effort increases.

Eventually, the yield becomes zero and the renewable resources may be driven to extinction because the rate of harvest exceeds the rate of generation of the resource sock.



Note that the yield effort curve is different from the growth function (in both of its variables on the X-Y plane).

iv. Maximum Sustainable Effort, Stock and Yield

It is now possible to find the maximum sustainable effort level by taking the derivative of the sustained yield function (7) with respect to effort E and setting the result equal to zero.

The maximum condition is

$$\frac{dY}{dE} = 0 \;\Rightarrow qk - 2\frac{q^2kE}{r} = 0 \Rightarrow E_{msy} = \frac{r}{2q}$$

where E_{msy}= the level of effort that is consistent with the maximum sustained yield.

Now, we can solve for the maximum sustainable sustained yield (E_{msy}) and the maximum sustainable stock (X_{msy}).

Substituting E_{msy} in (6) gives us $X_{msy} = \frac{k}{2}$

Substituting X_{msy} in (5) or (7) yields $Y_{msy} = \frac{rk}{4}$

II. Economic Equilibrium Analysis of Fishery

Many people believe that a renewable resource should be managed to produce its maximum sustainable yield. Economists do not agree that this is always sensible (but it may be in some circumstances). MSY ignores all social and economic considerations of renewable resource management.

Therefore, we need to convert this biological information to a net benefits formulation. The benefit function can be defined by multiplying Equation (7) by P, the price received for a unit of harvest. Assuming a constant marginal cost of effort (a) allows us to define total cost as equal to aE. Subtracting the total cost of effort from the revenue function produces the net benefits function.

$Net\ benefits = PqEk - \frac{Pq^2kE^2}{r} - aE$-- (8)

Since the efficient sustained effort level is the level that maximizes Equation (8), we can derive it by taking the derivative of Equation (8) with respect to effort (E) and setting the derivative equal to zero:

$Pqk - \frac{2Pq^2kE}{r} - a = 0$-- (9)

Rearranging terms yields

$E^* = \frac{r}{2q}(1 - \frac{a}{Pqk})$ -- (10)

Note that this effort level is smaller than that needed to produce the maximum sustainable yield. Can you see how to find the efficient sustainable harvest level?

Finally, we can derive the free-access equilibrium by setting the net benefits function in Equation (8) equal to zero and solving for the effort level.

Rearranging terms yields

$E^0 = \frac{r}{q}(1 - \frac{a}{Pqk})$

Note that E^0 is larger than the efficient sustained level of effort. It may or may not be larger than the level of effort needed to produce the maximum sustained yield. That comparison depends on the specific values of the parameters.

Management policies to overcome over-fishing:

- Open access fishery results in over-fishing and stock depletion (*tragedy of the commons).*
- Open –access level of effort (E^o) is larger than the efficient level of effort (E^e).

⇒Open-access stock depletion (S^o) is larger than efficient stock depletion (S^e).

- There are different management policies used to overcome overfishing:

✓ Individual transferable quota(ITQ)- allocating quota to licensed fishers - Quantity restrictions on catches

✓ Marine reserve – creating no fishing zone

✓ Fishing season regulations

✓ Technical restrictions on the equipment used - for example, restrictions on fishing gear, mesh or net size, or boat size.

✓ Establishing common ownership over the fishery