Natural resources

A simple classification

- Exhaustible: these resources are present in finite quantities and once used they are gone forever (mineral ores, coal, gas)
- Inexhaustible: these resources, once used, are naturally recycled or replenished (water, air, sunlight)

- Non-renewable: resources that cannot grow by themselves (e.g. water is inexhaustible, but is not renewable)
- Renewable: biological populations that can grow, but might be exhausted, driven to extinction

Managing the harvest of natural populations (renewable resources)

Overlogging in British Columbia (Canada)

Overfishing of jack mackerel in Chile

Tiger hunting

Overfishing in the Mediterranen

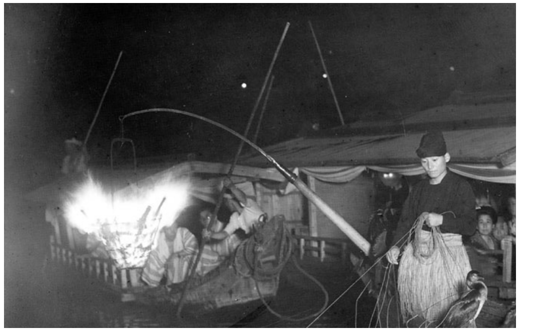
The value of biodiversity

direct	Biological resources (food, timber, fiber, medicines)
indirect	Ecosystem services Biological integrity
intrinsic	Recreational Cultural Aesthetic Spiritual

Overexploitment

Percent importance of extinction and endangerment causes for world birds.

	Extinct species	Endangered species
Habitat destruction	20%	60%
Alien species introduction	22%	12%
Hunting	18%	11%
Capture for other reasons (pets, zoos)	1%	9%
Disease	1%	1%
Pollutants and pesticides	0%	1%
Human disturbance	0%	2%
Accidental killing	1%	1%
Unknown	37%	3%
	100%	*100%*



Causes of endangerment in the USA. Percentage of species being endangered by each cause.

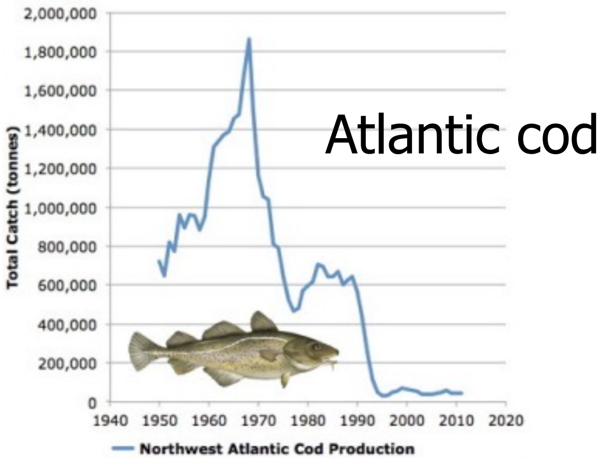
	All species	Vertebrates	Invertebrates	Plants
Habitat destruction and degradation	85%	92%	87%	81%
Exotic species introduction	49%	47%	27%	57%
Pollution	24%	46%	45%	7%
Overexploitation	17%	27%	23%	10%
Diseases	3%	11%	0%	1%

The passenger pigeon (extinct 1914)

Carolina parakeet
Conuropsis carolinensis

(declared extinct 1939)

The decline (and collapse) of marine fisheries



Baranov, F. I. 1918. К вопросу о биологических основаниях рыбного хозяйства (On the question of the biological basis of fisheries). Izvestiya otdela rybovodstva i nauchno-promyslovykh issledovanii 1 (1): 81–128.

$$C = \frac{F}{F+M}(1 - e^{-(F+M)T})N_0$$

Catch equation

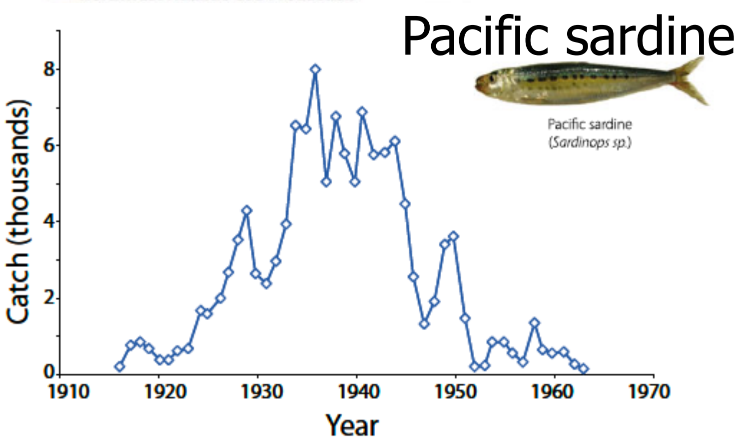
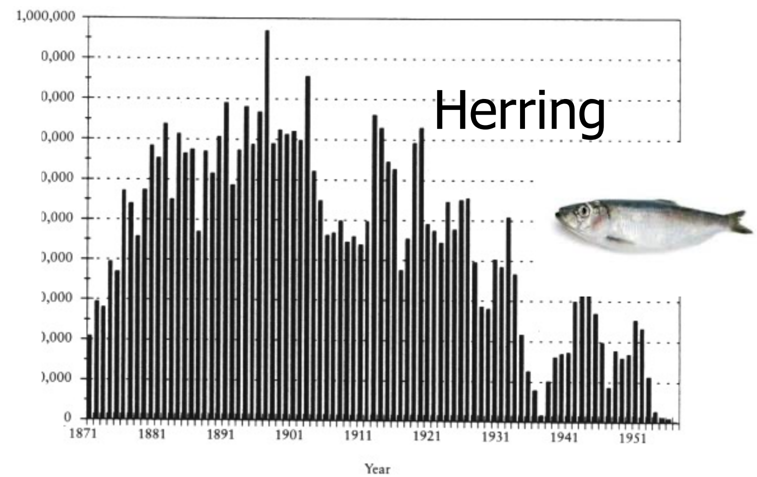
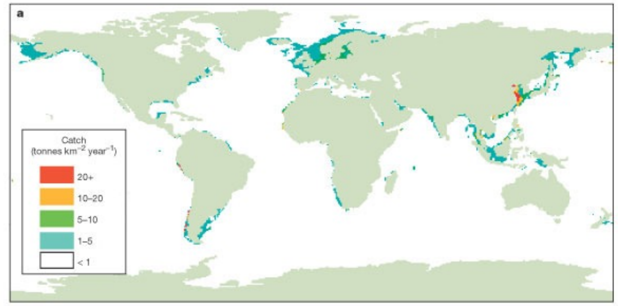
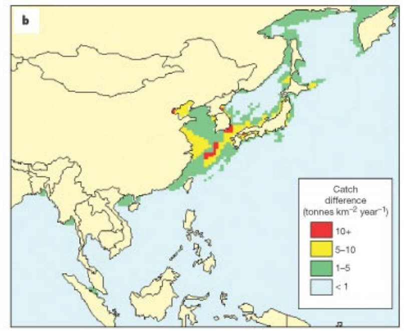


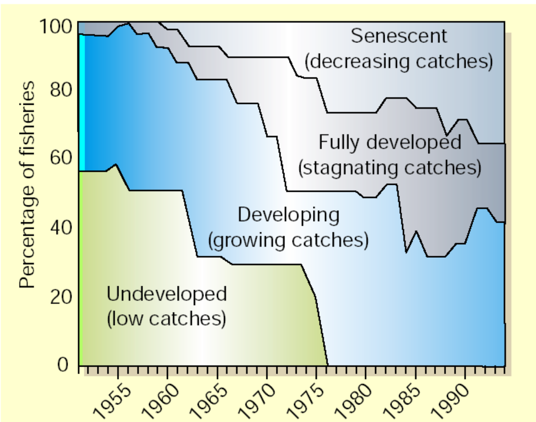
Fig. 8.21 Yearly sardine (*Sardinops caerulea*) catches along the Pacific shores of North America. Data after Murphy (1966)

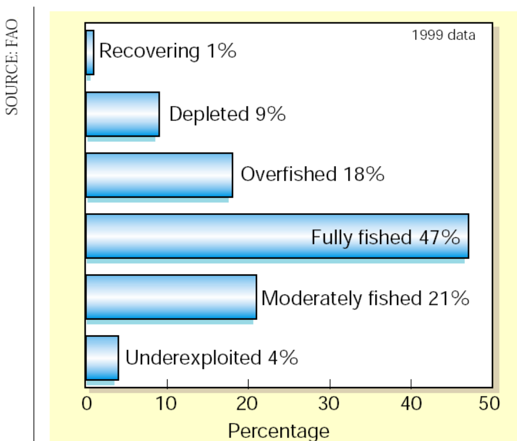


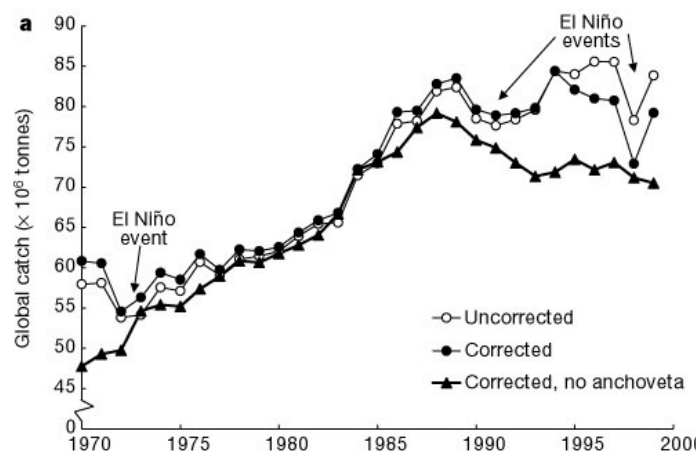
The decline of marine fisheries





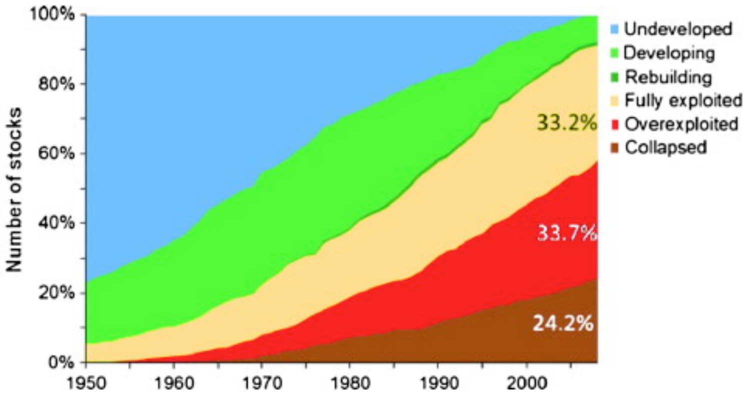


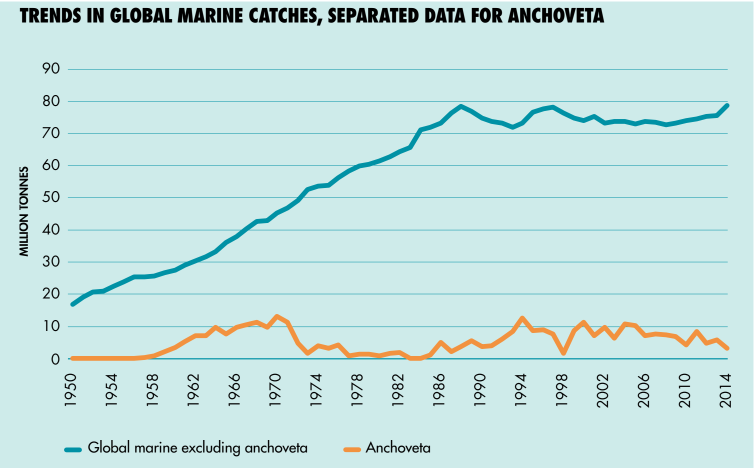




R. Watson and D. Pauly (2001) *Nature* **414**, 534 - 536

Overexploited stocks





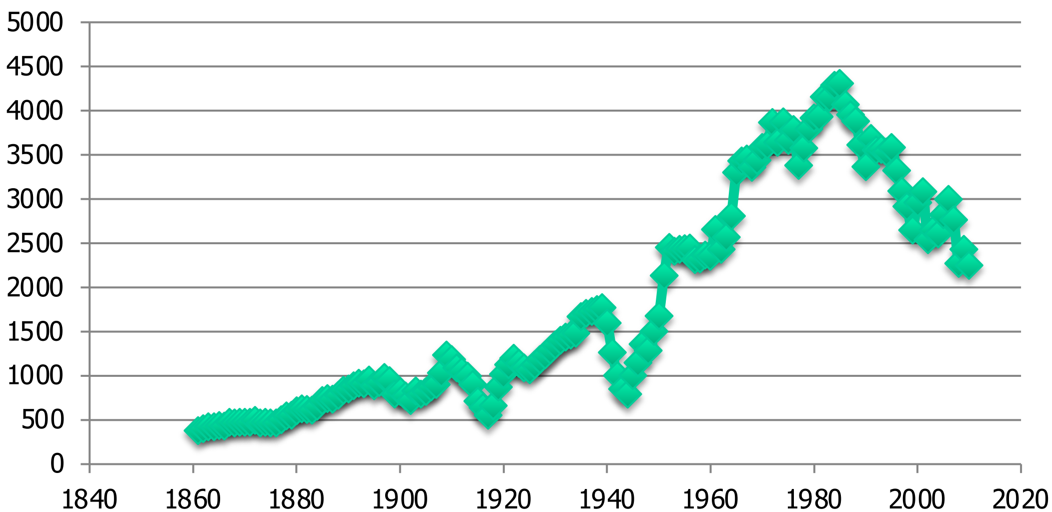
http://www.fao.org/3/a-i5555e.pdf

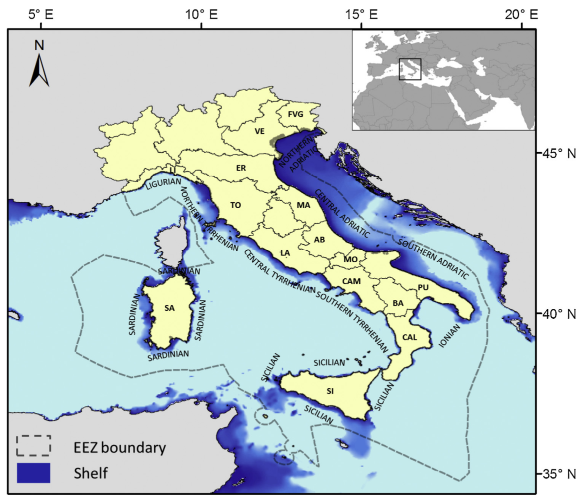
Stock	Peak Catch (year)	1981 Catch	Reference
Antarctic blue whales	29,000 whales (1931)	Nil	FAO[a] (1979)
Antarctic fin whales	27,000 whales (1938)	Nil	FAO[a] (1979)
Hokkaido herring	850,000 tons (1913)	Nil	Murphy (1977)
Peruvian anchoveta	12.3 million tons (1970)	0.3 million tons	IMARPE[b] (1974)
Southwest African pilchard	1.4 million tons (1968)	Nil	Butterworth (1980)
North Sea herring	1.5 million tons (1962)	Negligible	Saville (1980)
California sardine	640,000 tons (1936)	Nil	Murphy (1977)
Georges Bank herring	374,000 tons (1968)	Nil	Sinderman (1979)
Japanese sardine	2.3 million tons (1939)	17,000 tons (1973)	Murphy (1977)

[a] United Nations Food and Agriculture Organization.
[b] Institut del Mar del Peru.

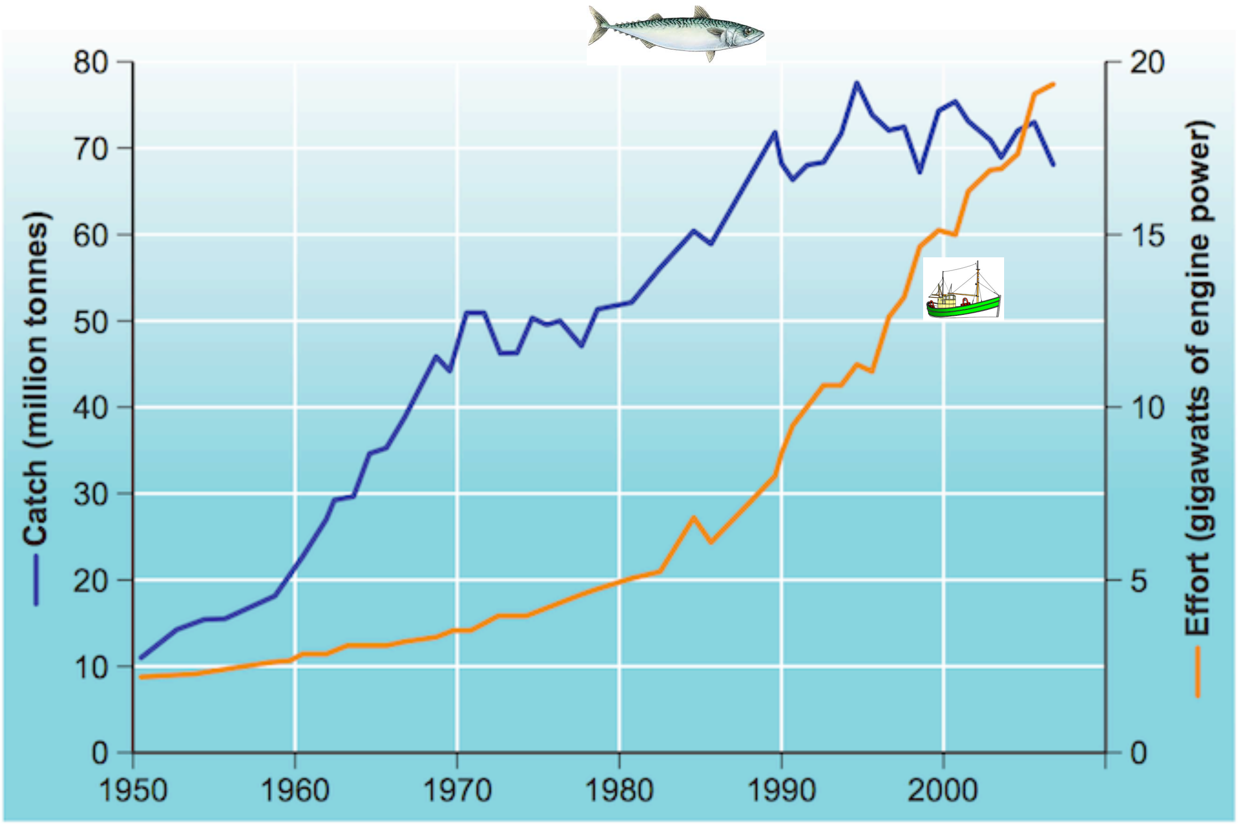
Fisheries in Italy

Total fishery yield Italy (hundreds of tonnes)
Fish, molluscs, crustaceans





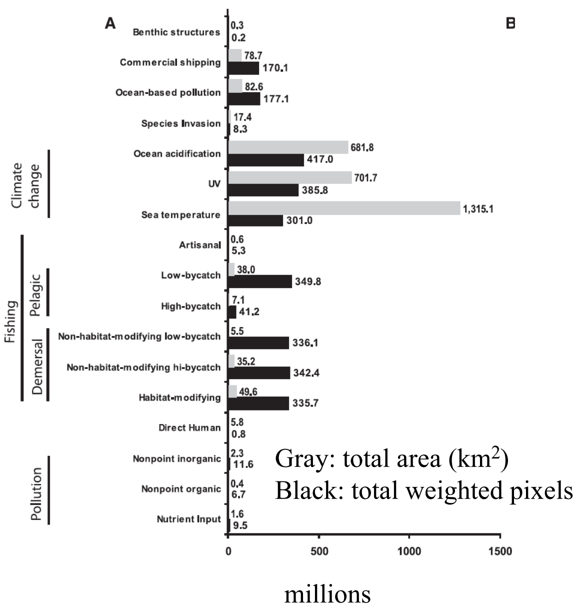
Yield vs. human effort

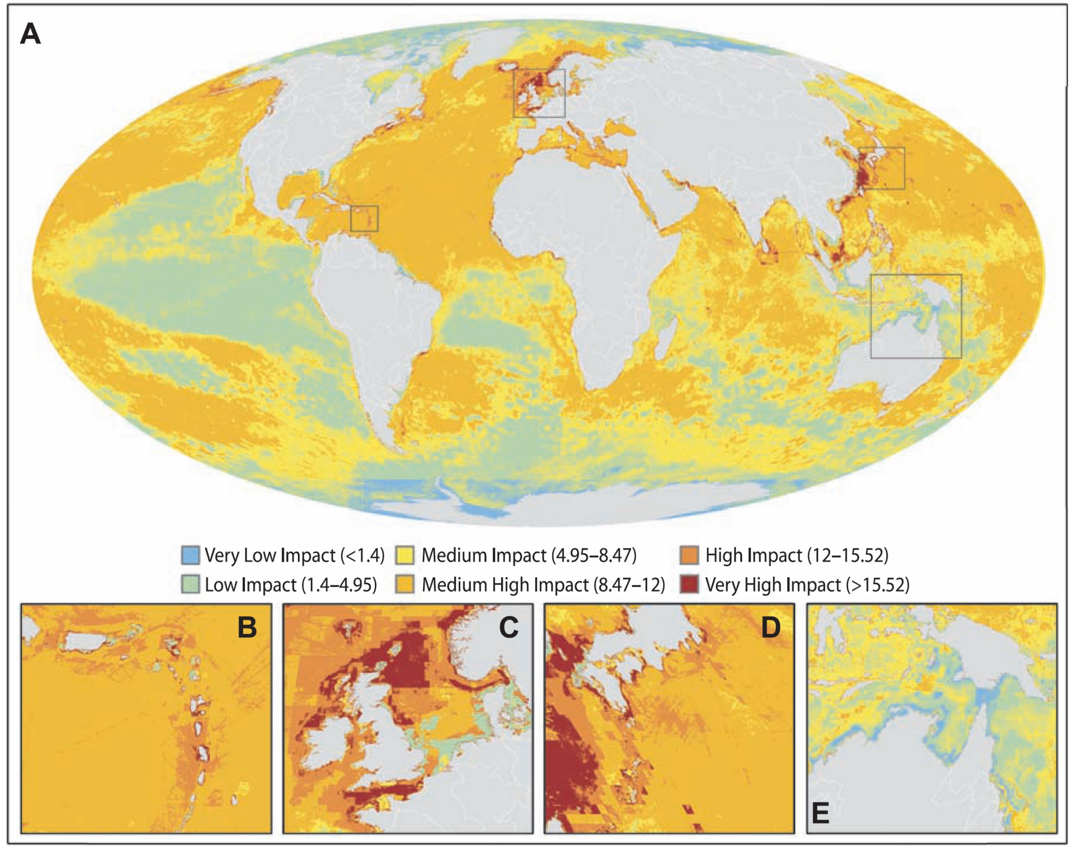


Pitcher, T.J., Cheung, W.W.L. Fisheries: Hope or despair? Mar. Pollut. Bull. (2013)

Cumulative human impact on oceans

Fig. 1. Global map (**A**) of cumulative human impact across 20 ocean ecosystem types. (Insets) Highly impacted regions in the Eastern Caribbean (**B**), the North Sea (**C**), and the Japanese waters (**D**) and one of the least impacted regions, in northern Australia and the Torres Strait (**E**).

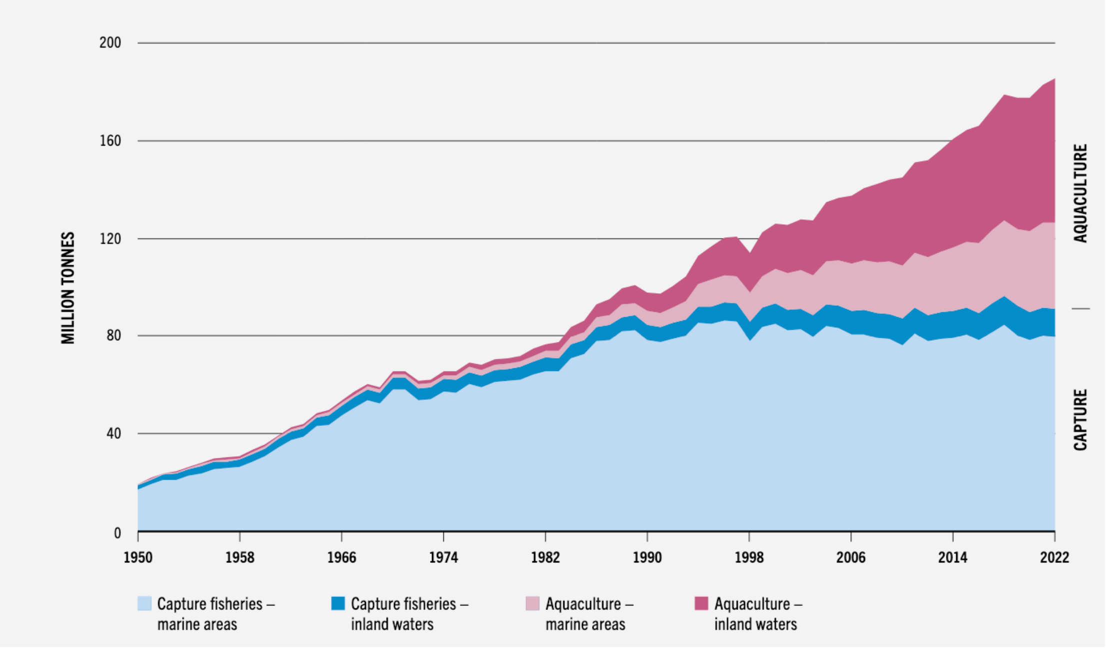




Halpern B.S. *et al.* 2008. *Science* 319: 948-952

The role of aquaculture

FIGURE 1 WORLD FISHERIES AND AQUACULTURE PRODUCTION OF AQUATIC ANIMALS



Fishing down the food web

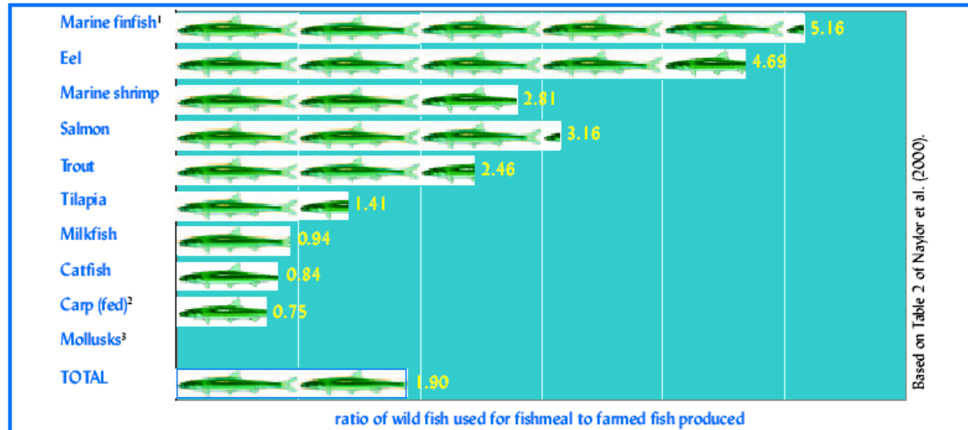
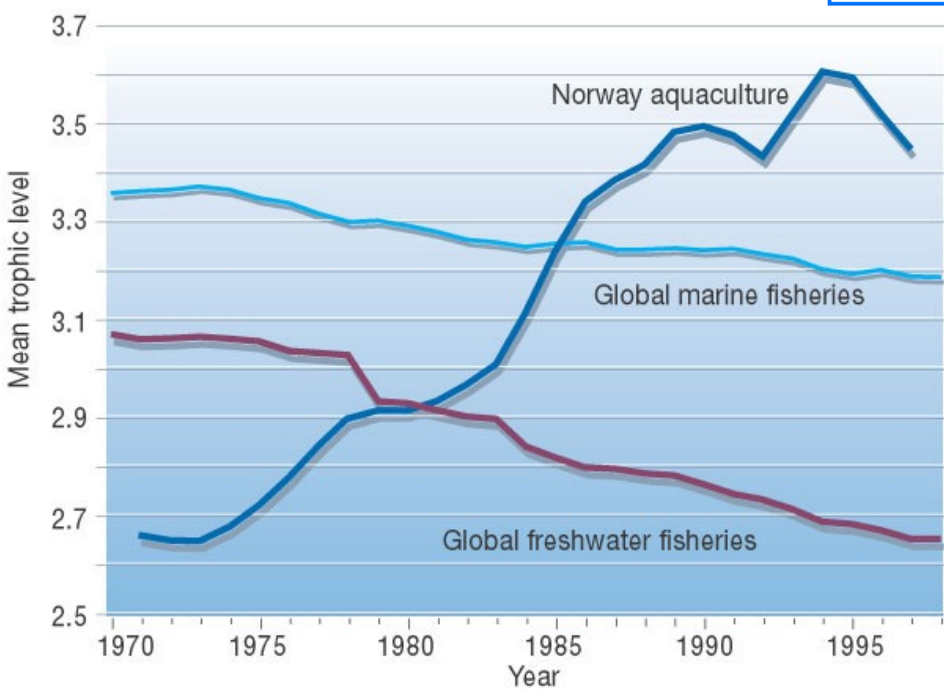


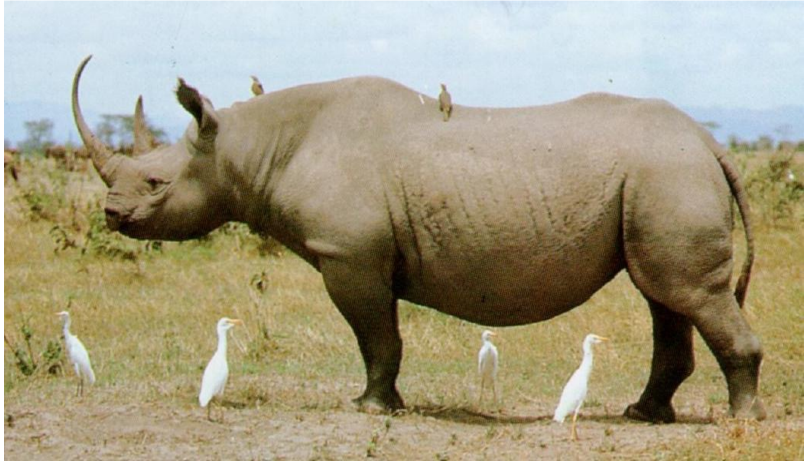
Figure 3 — Wild fish inputs used in feeds for the ten types of fish and shellfish most commonly farmed in 1997 presented as the ratio of wild fish used for fishmeal to farmed fish produced using compound feeds. In calculating the amount of wild fish used in compound feeds, we assumed a 5:1 conversion rate of fish to fishmeal and that one-sixteenth of fishmeal is obtained from processing by-products. [1]Marine finfish (other than salmon, which is listed separately because of its market significance) include flounder, halibut, sole, cod, hake, haddock, redfish, seabass, congers, tuna, bonito, and billfish. [2]Fed carp refers to carp species that are sometimes fed compound feeds. Filterfeeding carp (silver carp, bighead carp, and catla) are not fed compound feeds and are not included here. [3]Mollusks are filter-feeders and are not fed compound feeds.



Endangered big African mammals

Population size estimates for the black rhinoceros and the African elephant

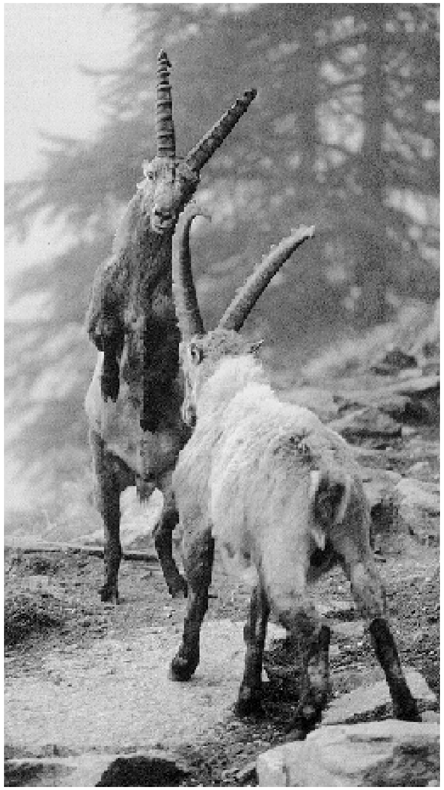
Region	Black rhino			African elephant	
	1980	**1984**	**1987**	**1981**	**1987**
East Africa	5,950	3,895	808	429,521	190,720
Central Africa	3,125	285	40	436,200	375,800
South Africa	5,700	4,620	2,955	311,000	181,600
West Africa	-	-	-	17,610	16,290
TOTAL	14,775	8,800	3,803	1,194,331	764,410



The black rhino status

•**1800's**: hundreds of thousands; fairly continuous throughout much of sub-Saharan Africa
•**1970**: 65,000; small, scattered, isolated populations.
•**1990**: 3,800; declined 94% in 20 years.
•**1992-1995**: 2400-2500; stable
•**1999**: 2700; slight increase
•**2001 - present**: 3,100 (2001 = latest estimate); slight increase continues.

The ibex *Capra ibex ibex*



1816: only 100 animals in Gran Paradiso
today: 31,000 animals in the Alps

The Alaska salmon


Sockeye salmon


A salmon purse-seiner in Alaska


Coho salmon

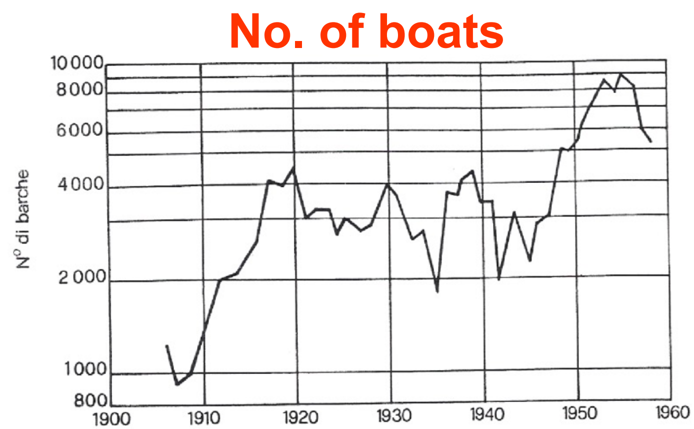


Fig. 1.2 - Numero di barche da pesca usate per la cattura del salmone in Alaska tra il 1906 e il 1959 (da Cooley, 1963).

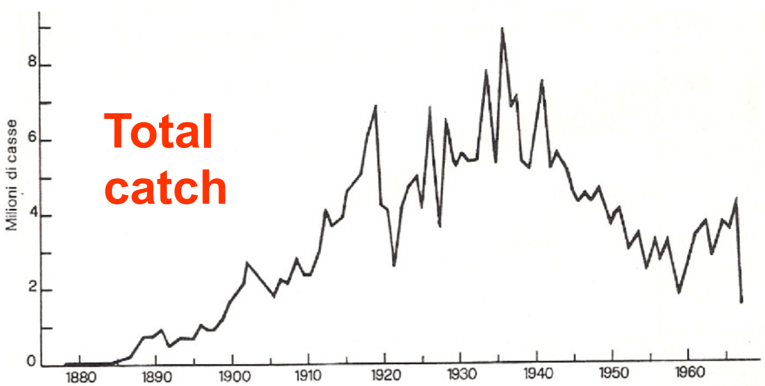


Fig. 1.1 - Numero totale di casse di salmone in scatola prodotte in Alaska tra il 1878 e il 1967 (da Fishery Statistics of the United States).

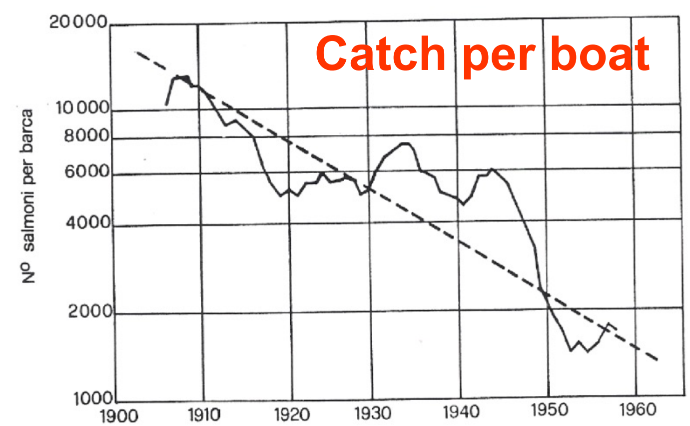
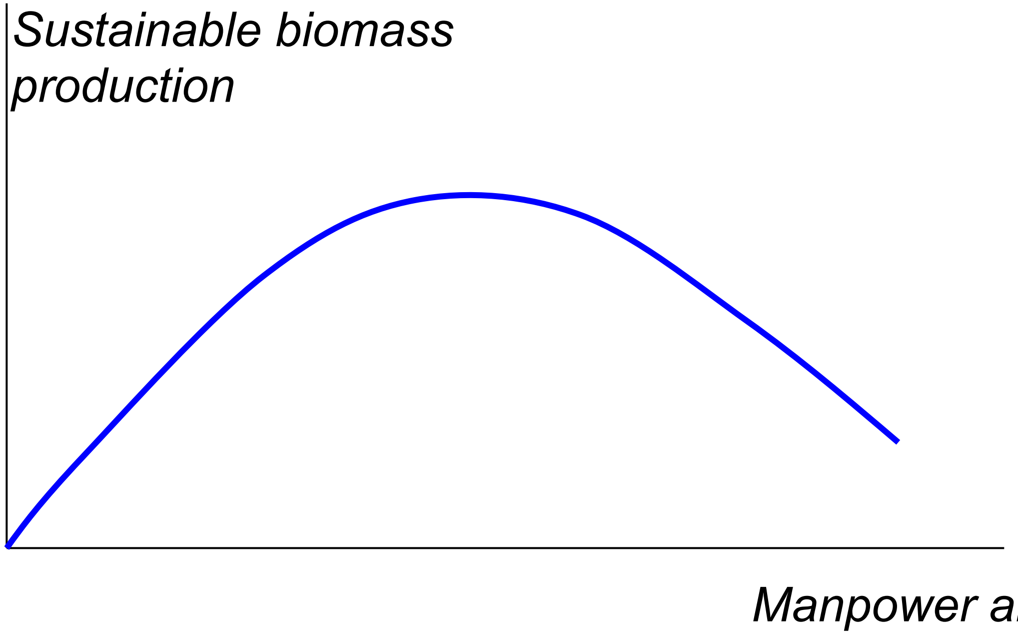


Fig. 1.3 - Numero medio di salmoni catturati da una barca da pesca in Alaska tra il 1906 e il 1959 (da Cooley, 1963).

The main problem

- **The yield curve related to exploitation of biological renewable resources is decreasing at high values of the factors of production**



grazing of common land

- **Many renewable resources are open access (commons)**

The tragedy of the commons
(Garret Hardin, 1968, Science, 162: 1243-1248)

Fishermen's dilemma: the game

Fisherman A

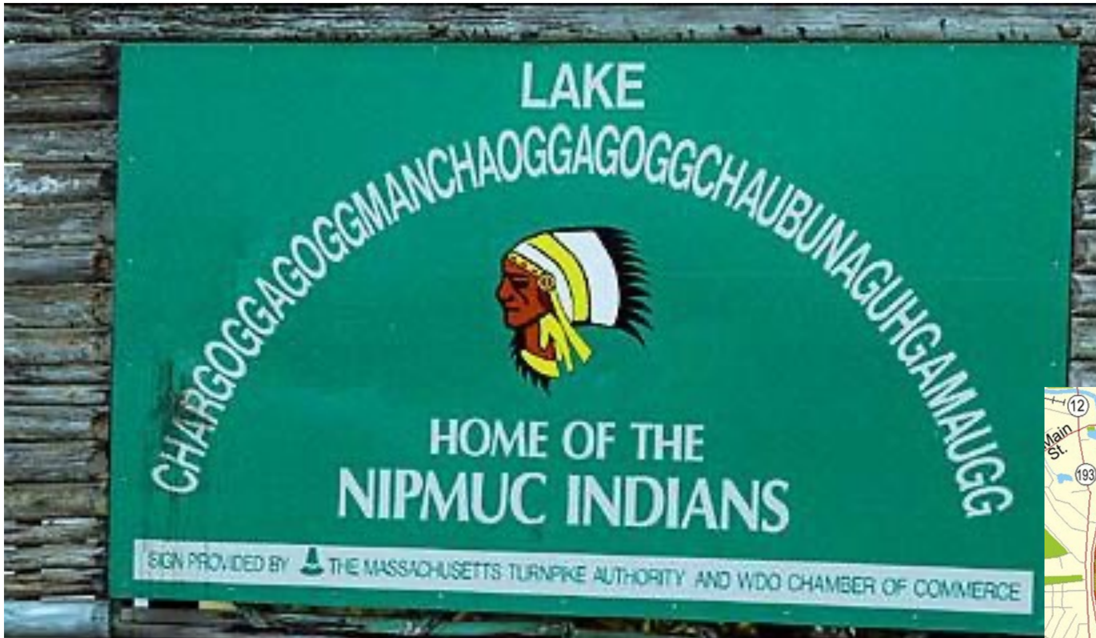
Fisherman B

Economic benefits	Preserve	Overexploit
Preserve	3,3	4,1
Overexploit	1,4	2,2

C. Clark (1981) *BioScience* **31**:231

Without regulation

- **Biological overexploitation**
- **Economic inefficiency**



Southern Massachusetts

"You fish on your side;
I fish on my side;
nobody fishes in the middle."

Neubert (2004) *Oceanus magazine* **43**(2)

Rational management: what does it mean?

- Maximize biomass yield
- Maximize net economic benefit
  - over a given time horizon
  - in the long term (sustainability and intergenerational equity)
- Minimize the risk of extinction and ecosystem deterioration

- Objectives and constraints

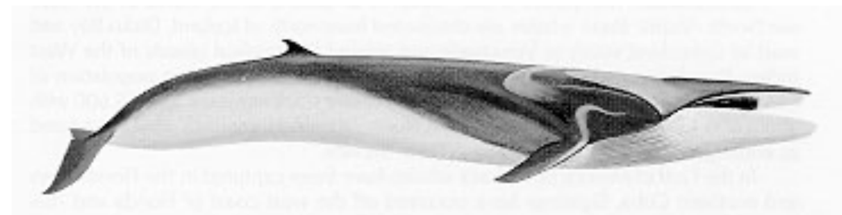
Regulation methods

- Non exclusive
  - Total catch quotas
  - Restriction on age, size, sex
  - Restriction on employed technology (e.g. fishing gear, engine power, etc.)
  - Restriction on fishing and hunting seasons and areas
- Exclusive
  - Licenses
  - Allocated catch quotas
- Economic
  - Taxes
  - Subsidies
  - Transferable quotas

The dynamics of exploited populations

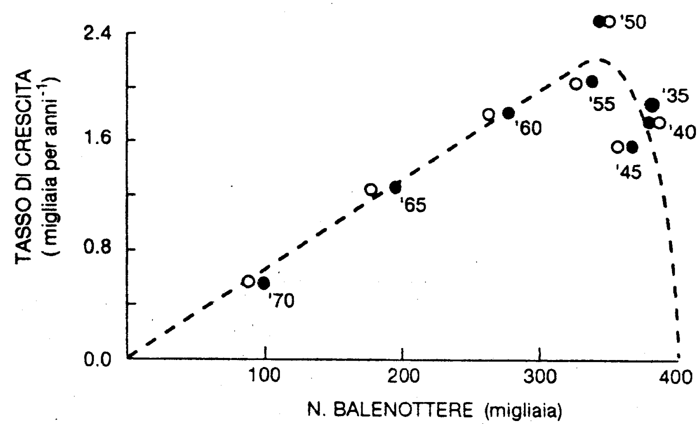
- Continuous reproduction

$$\frac{dx}{dt} = F(x) - h = xR(x) - h$$

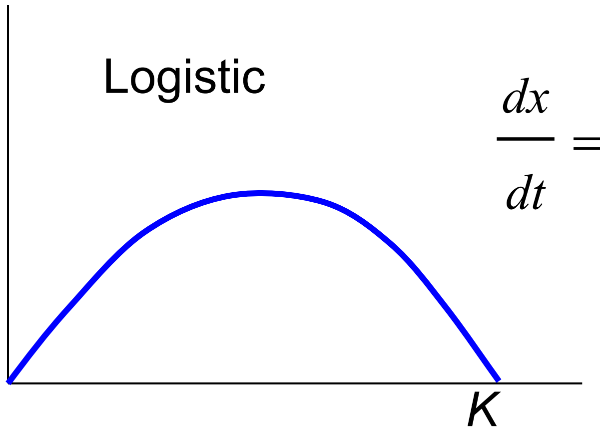


Fin whale (*Balaenoptera physalus)*

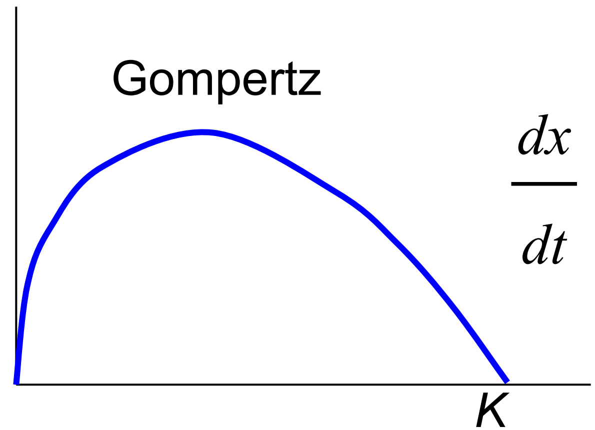
x = resource biomass
F(x) = resource growth rate
R(*x*) = growth rate per unit biomass
h = harvesting rate



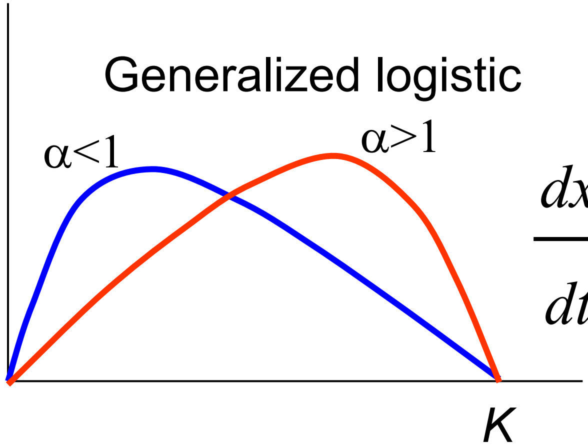
Resource growth rates: examples



$$\frac{dx}{dt} = rx\left(1 - \frac{x}{K}\right)$$



$$\frac{dx}{dt} = rx \log \frac{x}{K}$$



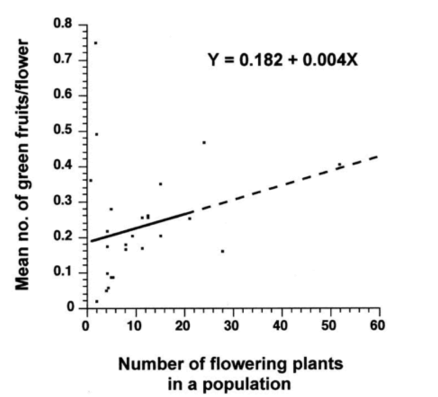
$$\frac{dx}{dt} = rx^{\alpha}\left(1 - \frac{x}{K}\right)$$

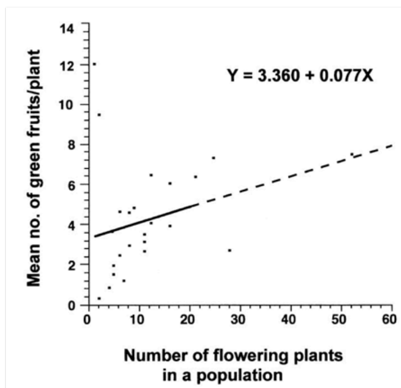
or

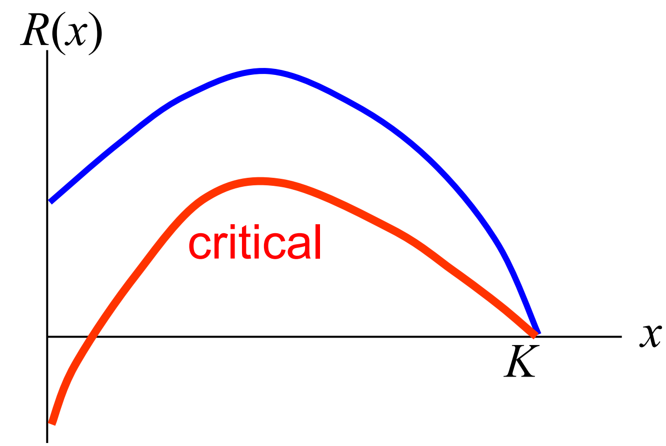
$$\frac{dx}{dt} = rx\left(1 - \frac{x}{K}\right)^{\alpha}$$

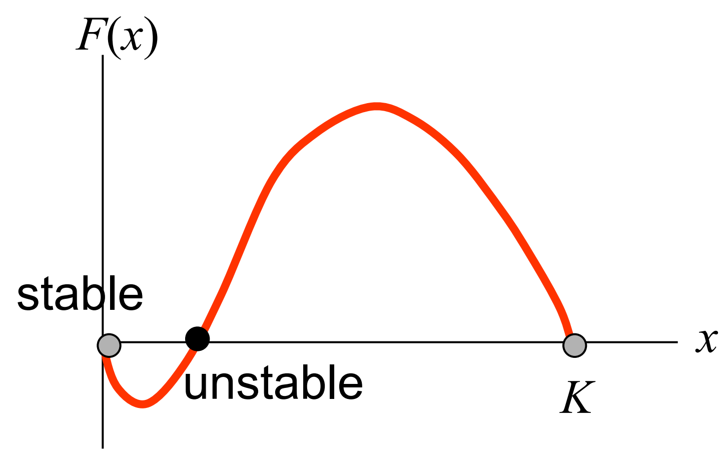
Depensation

Reproductive success as a function of density in American ginseng (*Panax quinquefolium* L.)









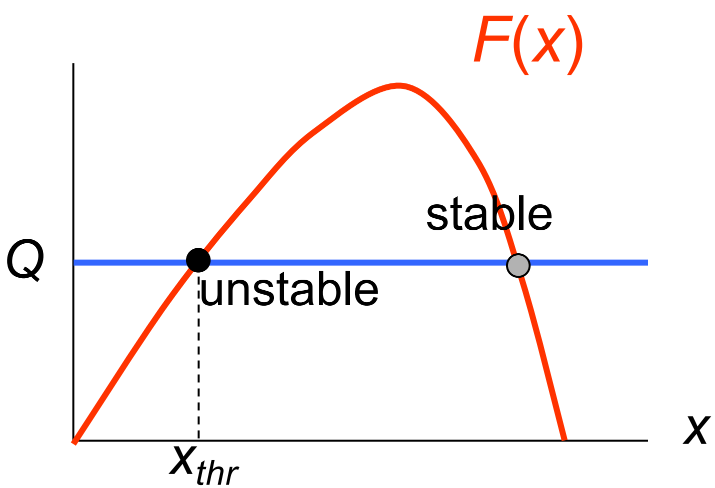
Total catch quotas

In principle $h(t) \leq Q(t)$, in practice $h(t) = Q$ for long periods

$$\frac{dx}{dt} = F(x) - Q$$

Peruvian anchoveta: 10 million tonnes/year

Q = quota (e.g., 100,000 tons per year)



If quota is blindly used under any condition resource can be driven down to extinction whenever disturbance pushes x below threshold x_{thr}

Harvesting rate *h* and effort *E*

Effort *E* is some suitably defined measure of the harvesting stress on the resource being exploited

- **No. of operating vessels**
- **No. of hunters**
- **Tonnage**
- **Labour force employed**
- **Fuel consumption**
- **Capital invested in the harvesting activity**
- **A combination of all these**

Obviously $h = g(E,x)$ with *g* increasing function of both *E* and *x*

Very often we can assume $h = qEx$ with *q* being the catchability coefficient (depends on technology)

Catch per unit effort $h/E = qx$; if *q* is constant CPUE proportional to population size or biomass *x*

Fishing effort and CPUE in Italy

C. Piroddi et al. / Fisheries Research 172 (2015) 137–147

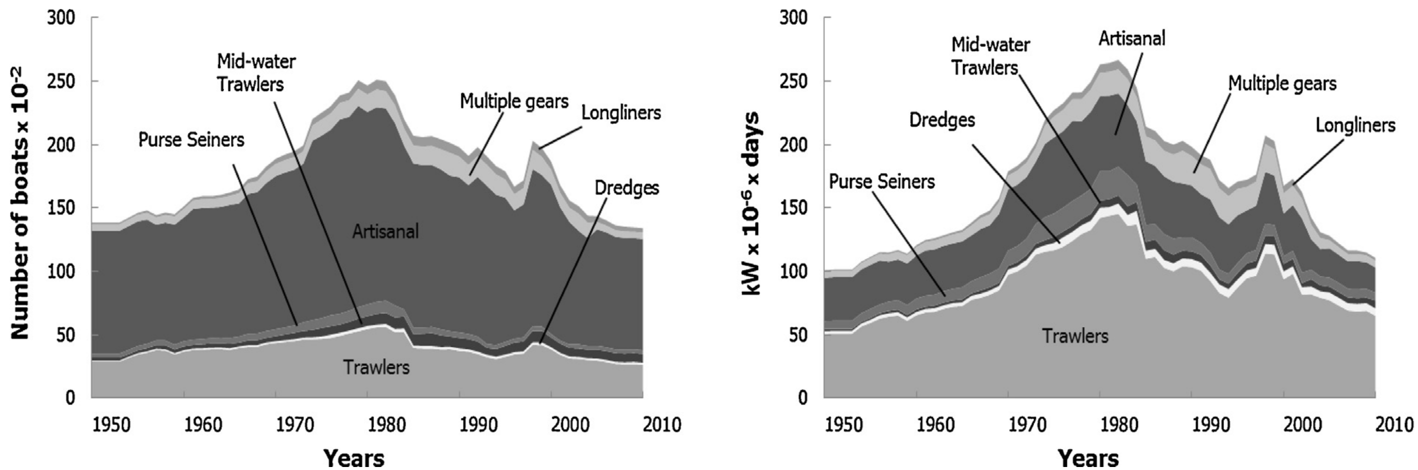


Fig. 5. For the whole of Italy: b) reconstructed total number of fishing boats; and b) reconstructed total fishing effort (kW days^{-1}) per gear type.

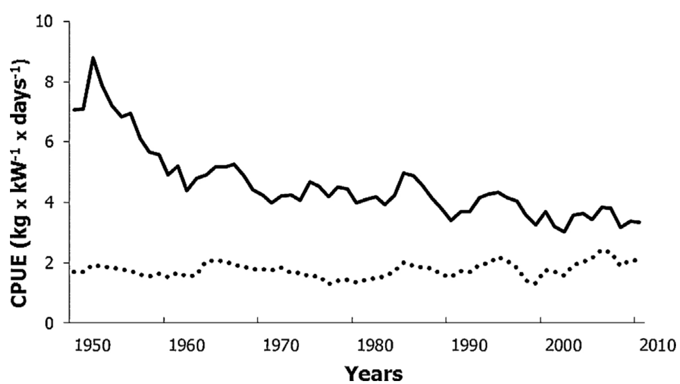
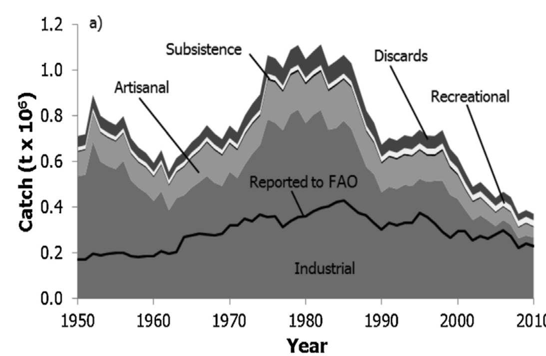


Fig. 6. Catch per unit of effort (kg kW^{-1} days^{-1}) for the whole of Italy for the 1950–2010 period using the reconstructed catches and effort time series (black line) and catches reported by the FAO on behalf of Italy with the reconstructed effort (dotted line).



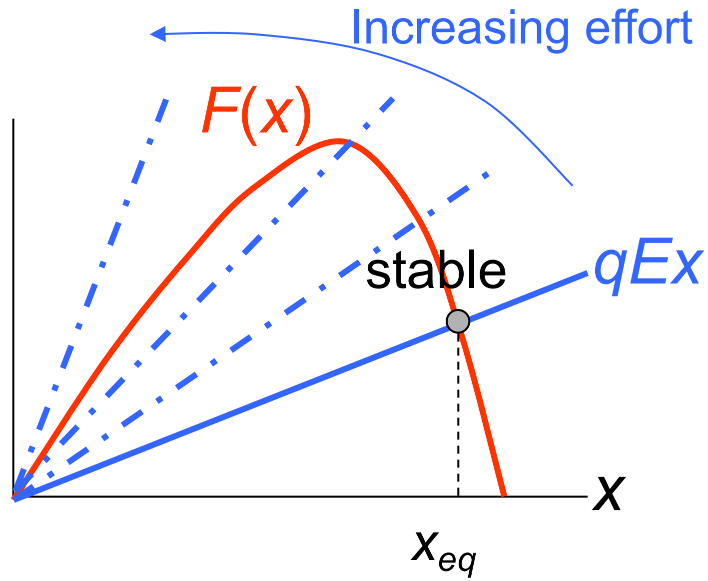
Using a constant effort policy

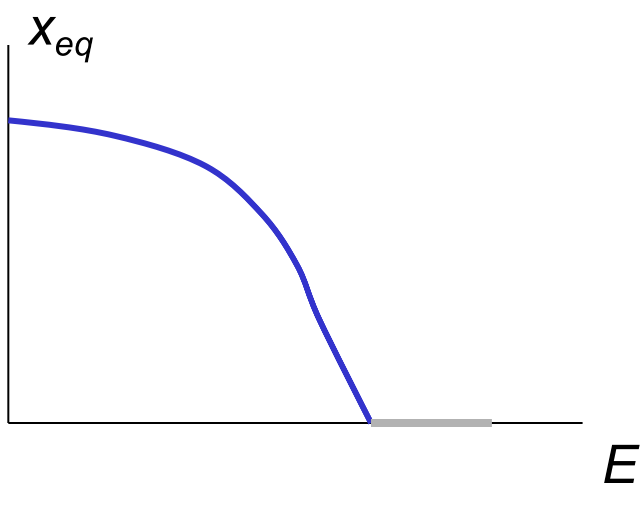
In principle $E(t) \leq E_t$. in practice $E(t) = E$ for long periods

$$\frac{dx}{dt} = F(x) - qE(t)x$$

$E(t)$ = effort at time t

Let $E(t) = E$ = constant (a certain number of vessels or hunters operates a certain number of days every year forever)



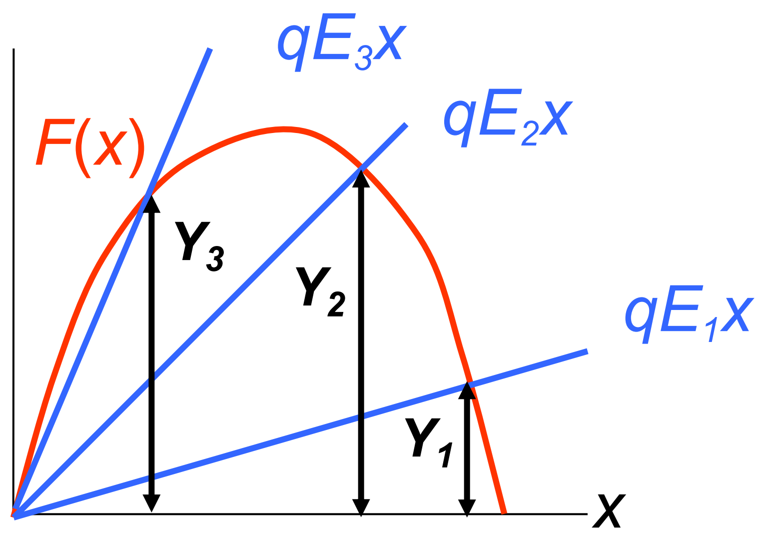


Sustainable yield

We define <u>sustainable yield</u> *Y* the constant harvesting rate that is obtained at a stable equilibrium by employing a constant effort *E*

$$Y = qEx_{eq}$$

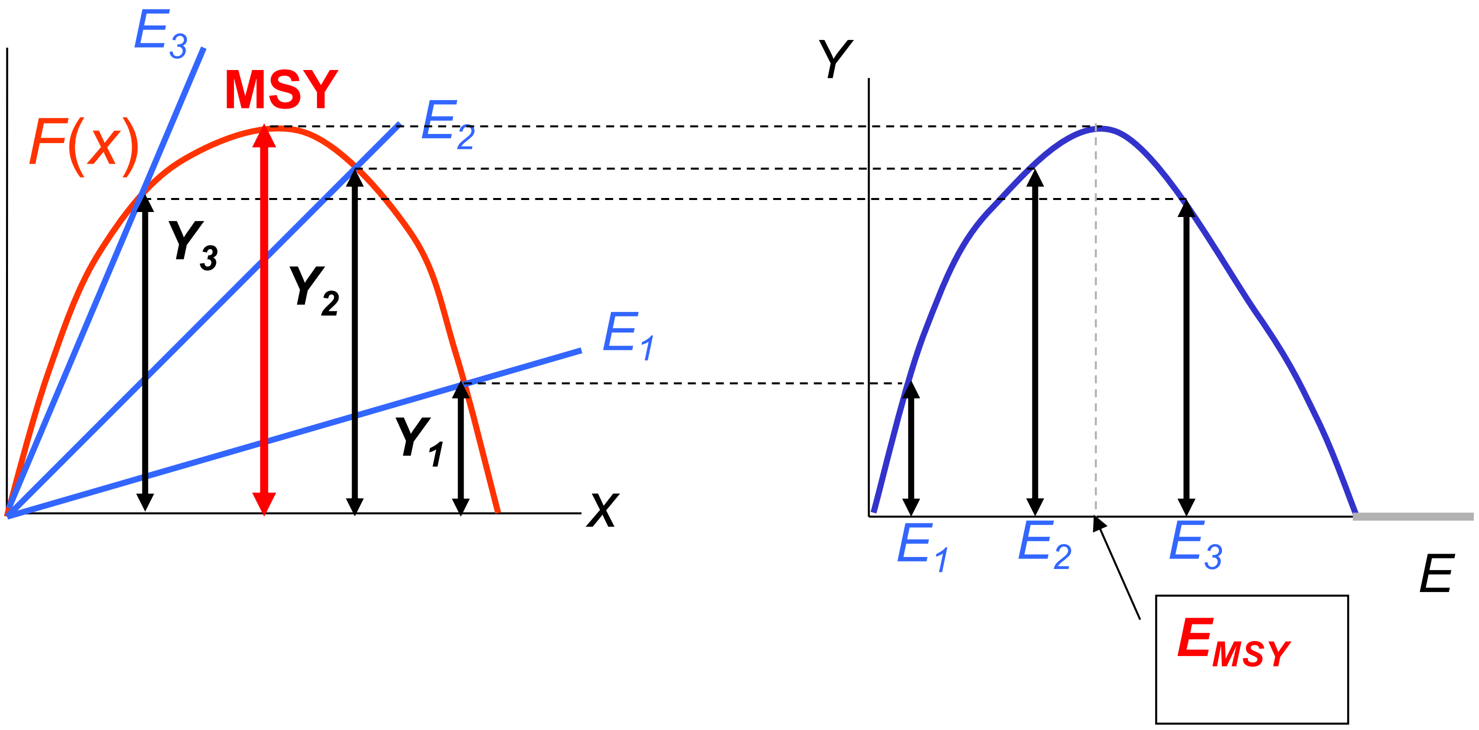
where x_{eq} is the biomass at equilibrium corresponding to effort *E*



$$Y = F(x_{eq}) = qEx_{eq}$$

$$E_1 < E_2 < E_3$$

Production curves and MSY



The effort E_{MSY} is the one that provides the Maximum Sustainable Yield (MSY).

MSY corresponds to the maximum natural growth rate.

$E > E_{MSY}$ corresponds to *biological overexploitation*

The Schaefer model

$$\frac{dx}{dt} = rx(1 - x/K) - qEx$$

$$r = 2.61 \text{ year}^{-1}$$
$$K = 1.34 \cdot 10^{8} \text{ kg}$$
$$q = 3.8 \cdot 10^{-5} \text{ fishing days}^{-1}$$

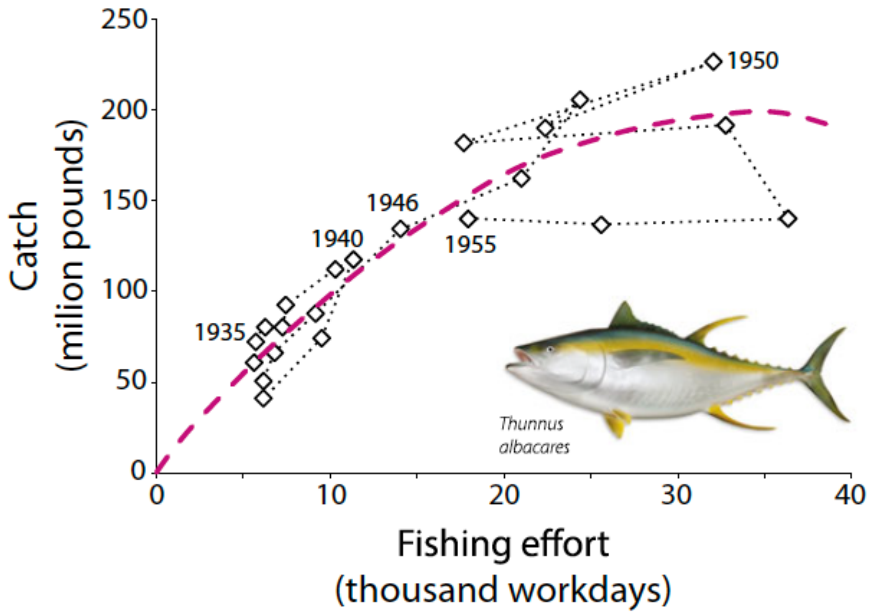
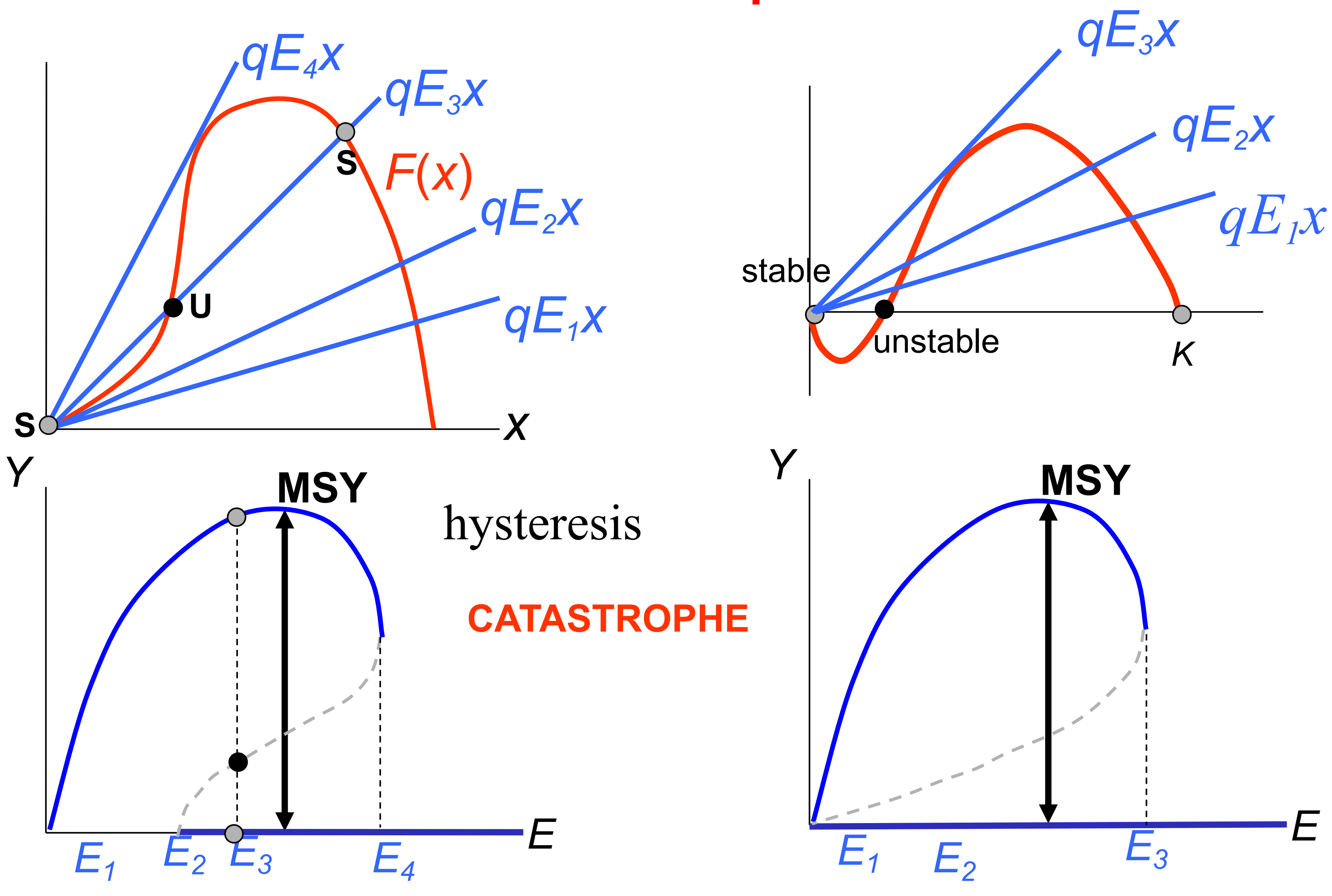


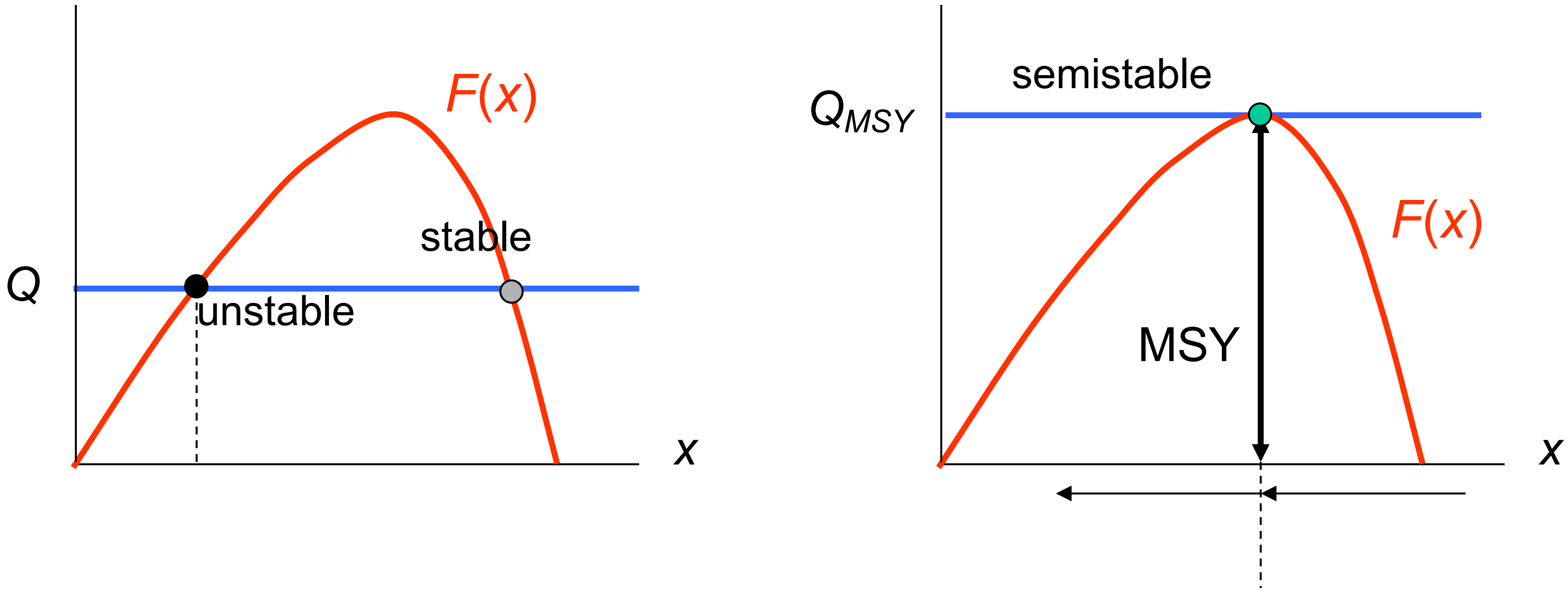
Fig. 8.14 Efforts and catches of *yellowfin* tuna (*Thunnus albacares*, inset) in eastern Pacific between 1934 and 1955. The parabola is the estimated relationship between effort and sustainable yield (Schaefer 1967)

$$E_{MSY} = \frac{r}{2q} = 34300 \text{ days}$$
$$x_{MSY} = \frac{K}{2} = 67 \text{ million kg}$$
$$MSY = \frac{rK}{4} = 87400 \text{ tonnes per year}$$

The effect of depensation



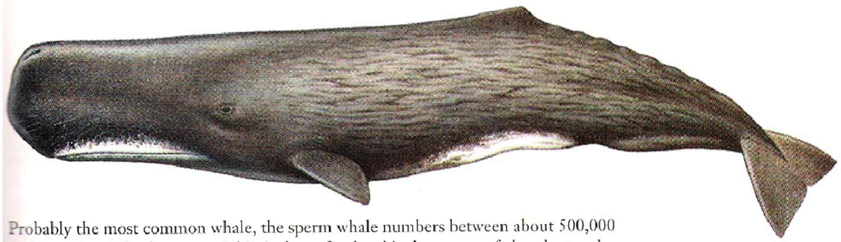
MSY and quotas



The combination of fixed quotas with MSY without an independent estimation of resource biomass *x* is to be avoided

Most commonly caught whales

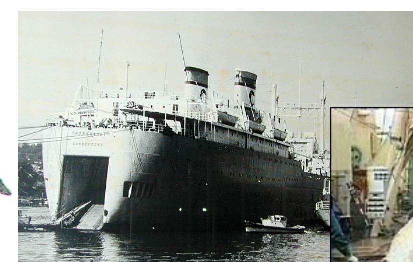
The "youngest" whale species, the grey whale has been around for 100,000 years, and is the only whale species to feed off the ocean bottom.



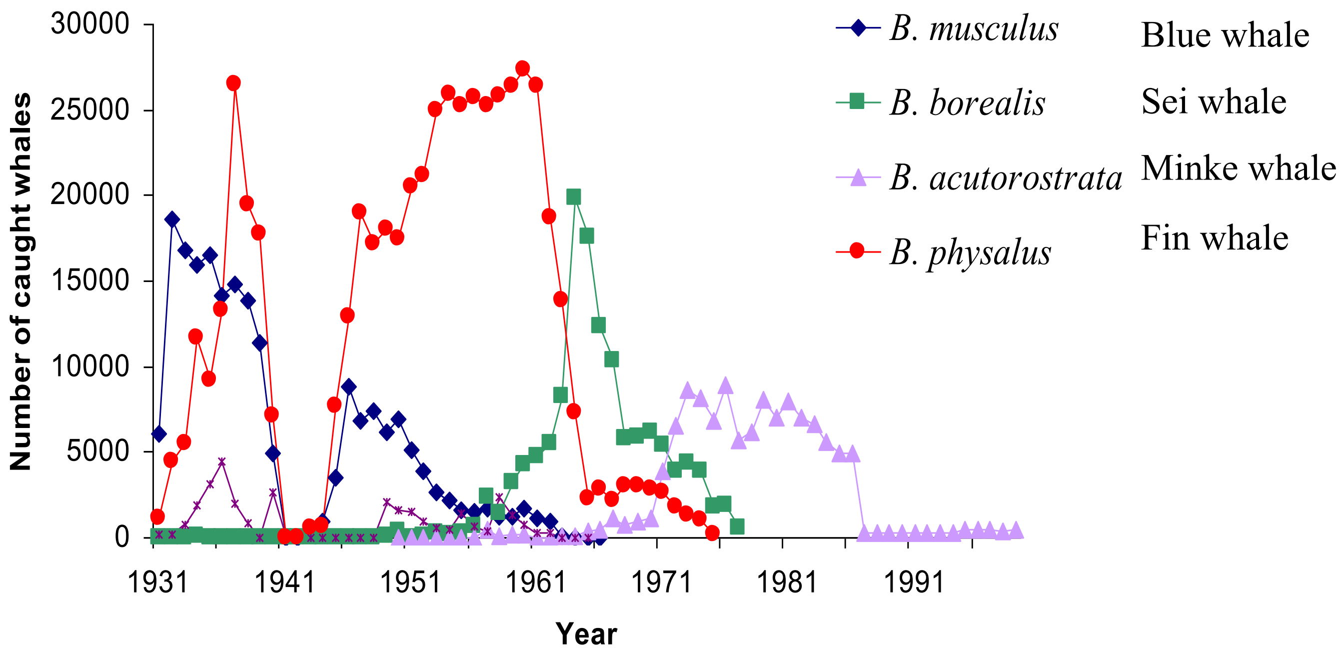
Probably the most common whale, the sperm whale numbers between about 500,000 and 2 million. The fatty material in its huge forehead is the source of abundant and high-quality oil.

The fin whale is the second largest whale. Like its relative the blue whale, it has a streamlined shape that gives it speed of movement.

The blue whale is the world's largest living animal, and its moans are the loudest sounds made by any living animal.



The decline of past century whaling



A. Dobson (1996) *Conservation and Biodiversity*

Whaling and catch quotas

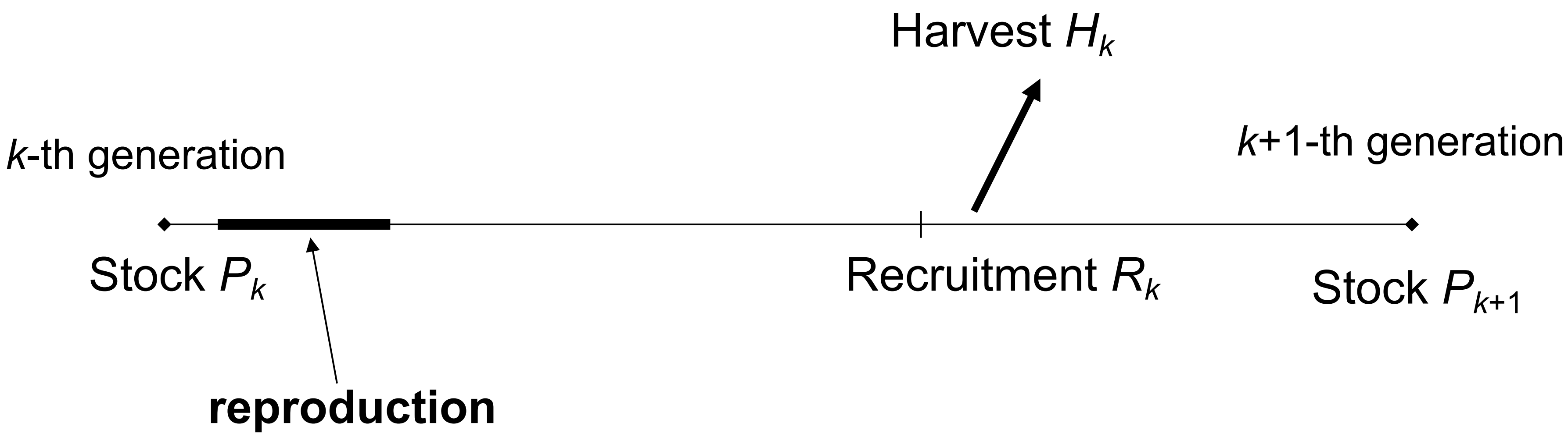
The Blue Whale Unit was used by the International Whaling Commission. The catch limit was expressed in BWUs, equal to 1 blue whale, 2 fin whales, 2½ humpback whales, or 6 sei whales. These ratios were based on the relative oil yields of the individual species.

Catch Limits set by IWC and actual catch (in blue whale units) of (*Balaenoptera* spp.)

Year	Catch quota	Actual catch
1946-47	16,000	15,338
1947-48	16,000	16,364
1948-49	16,000	16,007
1949-50	16,000	16,059
1950-51	16,000	16,413
1951-52	16,000	16,006
1952-53	16,000	14,855
1953-54	15,500	15,439
1954-55	15,500	15,300
1955-56	15,500	14,874
1956-57	14,500	14,745
1957-58	14,500	14,850
1958-59	15,000	15,301
1959-60	15,000	15,512
1960-61	---	16,433
1961-62	---	15,253
1962-63	15,000	11,306
1963-64	10,000	8,429
1964-65	---	6,986
1965-66	4,500	4,089
1966-67	3,500	3,511
1967-68	3,200	2,804
1968-69	3,200	2,469
1969-70	2,700	2,477
1970-71	2,700	2,469
1971-72	2,300	2,242

The dynamics of exploited populations

- Seasonal reproduction

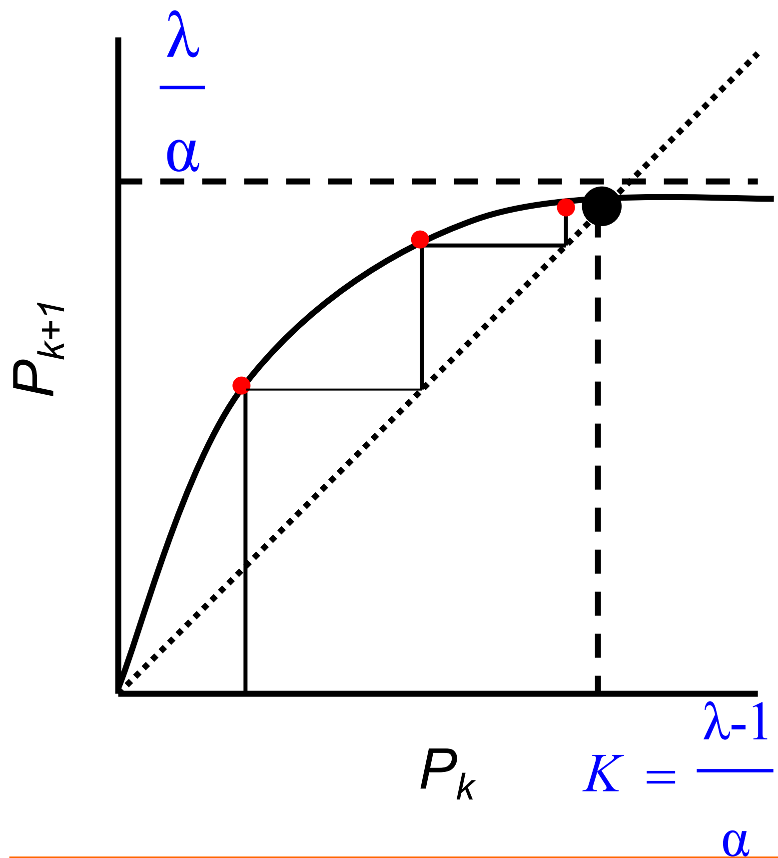


$$P_{k+1} = F(P_k) - H_k = P_k \Lambda(P_k) - H_k$$

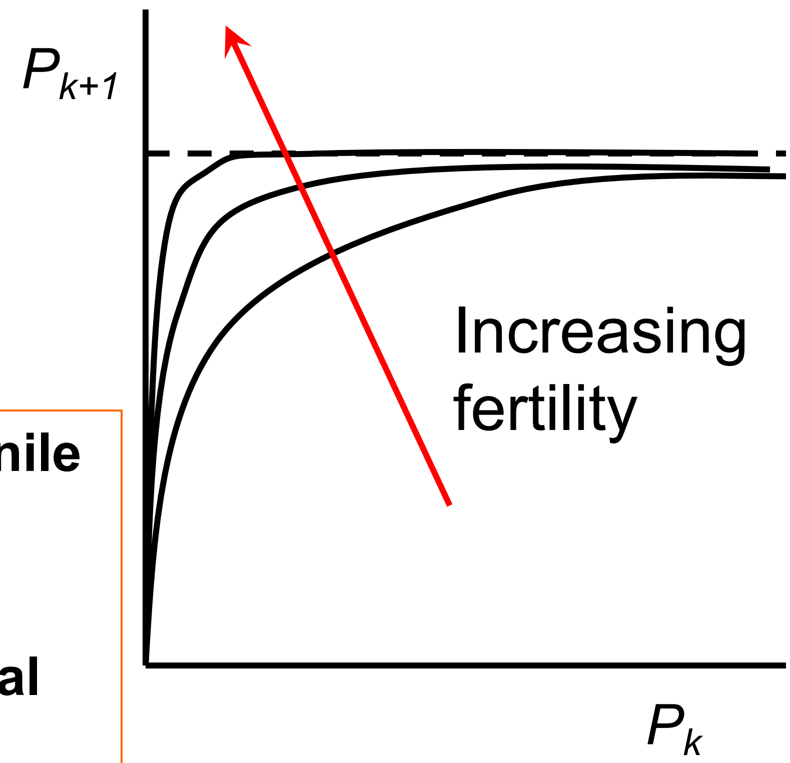
$F(P_k)$ = stock-recruitment relationship

$\Lambda(P_k)$ = per capita finite rate of increase

Beverton-Holt model (1957)



$$P_{k+1} = \frac{\lambda P_k}{1 + \alpha P_k}$$

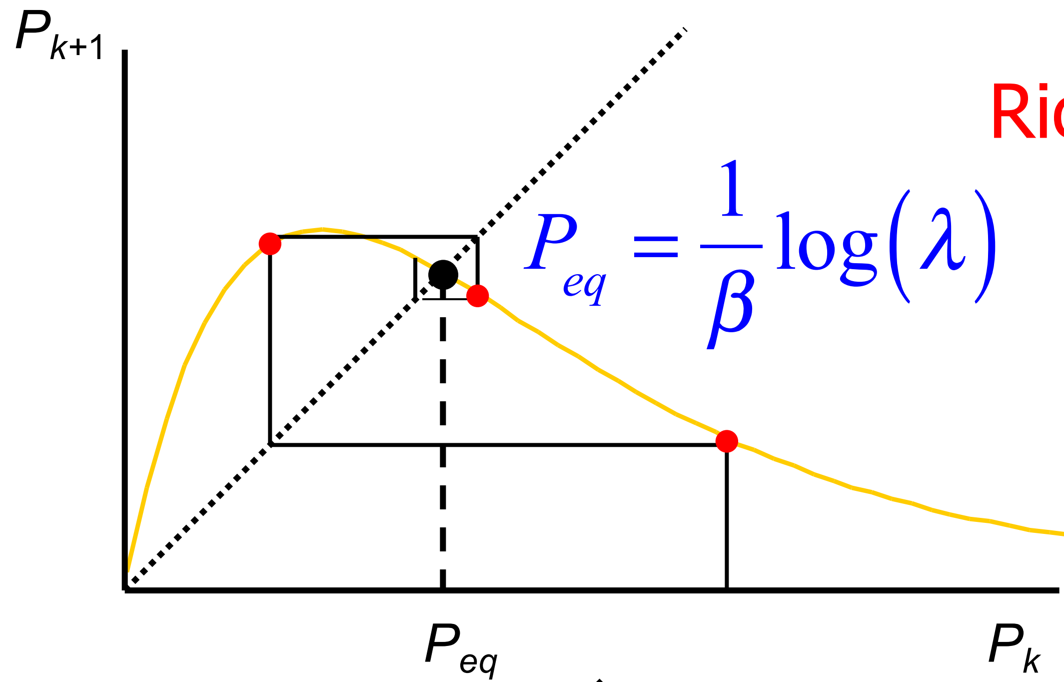


There is a bottleneck during juvenile development

In very fertile fish recruitment is practically independent of parental stock

Ricker model (1954)

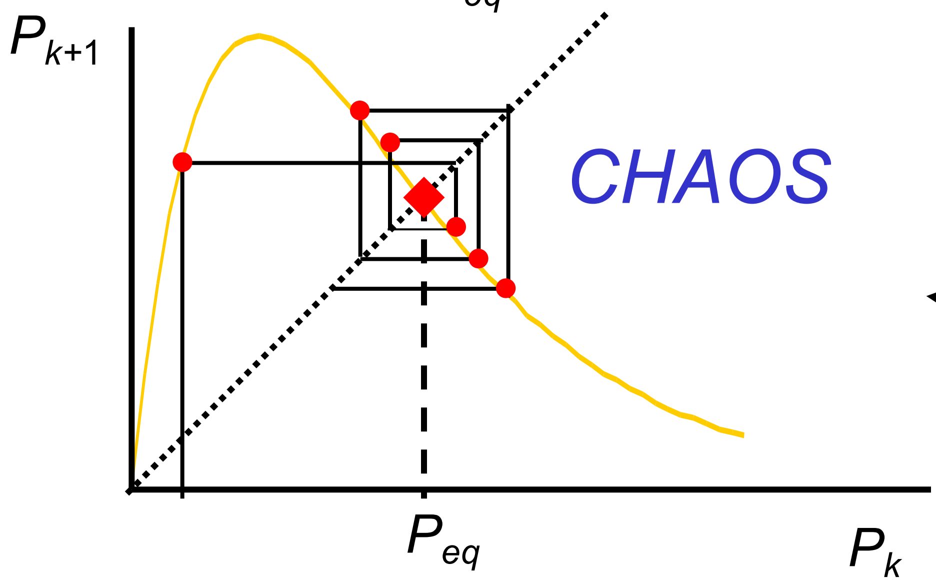
$$P_{k+1} = \lambda P_k e^{-\beta P_k}$$



$$P_{eq} = \frac{1}{\beta}\log(\lambda)$$

Overcompensation due to e.g.

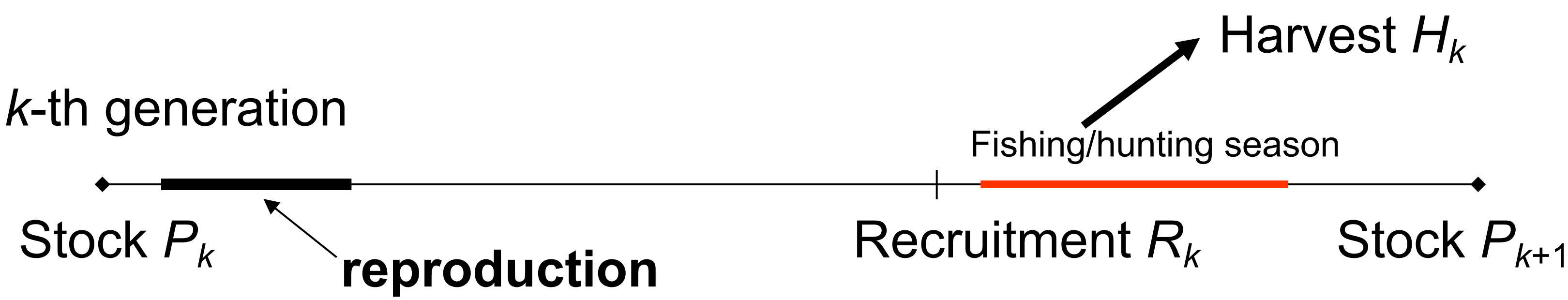
- **cannibalism**
- **disease**



CHAOS

More fertile species

Harvest and effort in discrete-time populations



$$P_{k+1} = F(P_k) - H_k = P_k \Lambda(P_k) - H_k$$

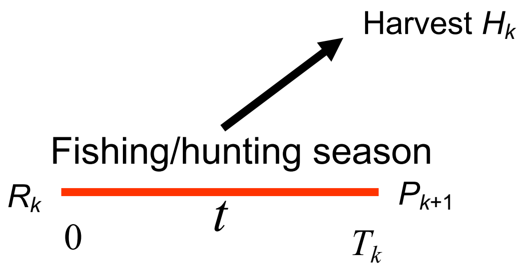
If the instantaneous harvest rate is $qE(t)N(t)$ then

$H_k = R_k(1 - \exp(-qE_k T_k))$

where E_k is the average effort (e.g., average number of vessels operating in year k) and T_k is the length of the harvesting season in year k.

E_k can be limited by granting only a few licenses.

Relationship between harvest and recruitment

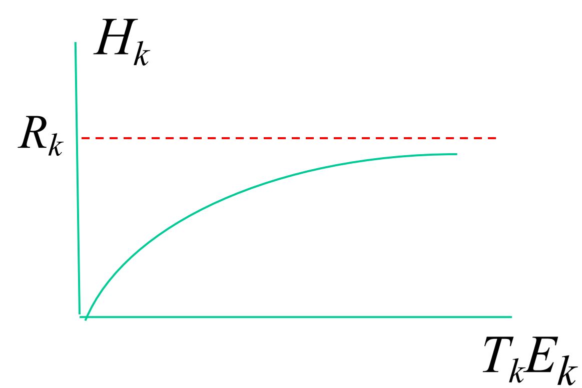


$$\frac{dx}{dt} = -qE(t)x$$

$$x(T_k) = P_{k+1} = x(0)\exp\left(-q\int_0^{T_k} E(t)dt\right) = R_k \exp\left(-qT_k \frac{1}{T_k}\int_0^{T_k} E(t)dt\right)$$

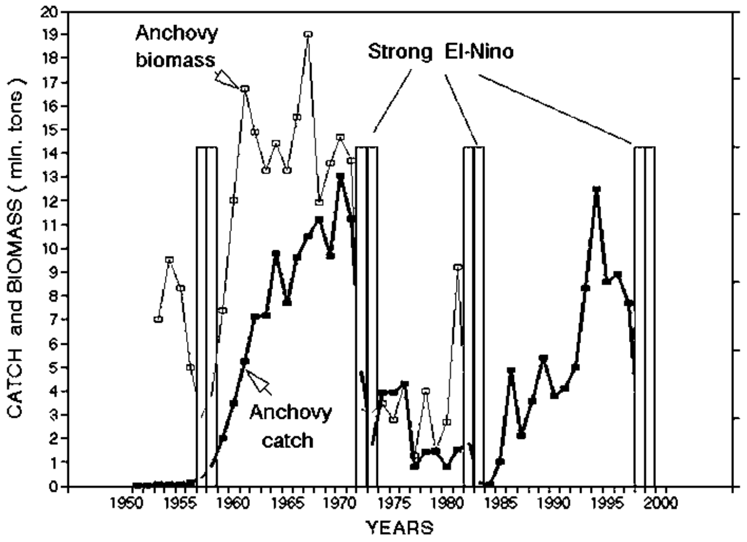
$$E_k = \text{average effort in season k=}\frac{1}{T_k}\int_0^{T_k} E(t)dt$$

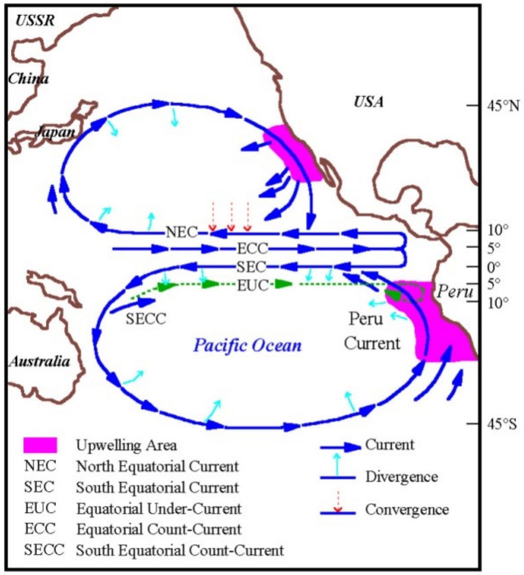
$$H_k = R_k - x(T_k) = R_k\left(1-\exp\left(-qT_kE_k\right)\right)$$



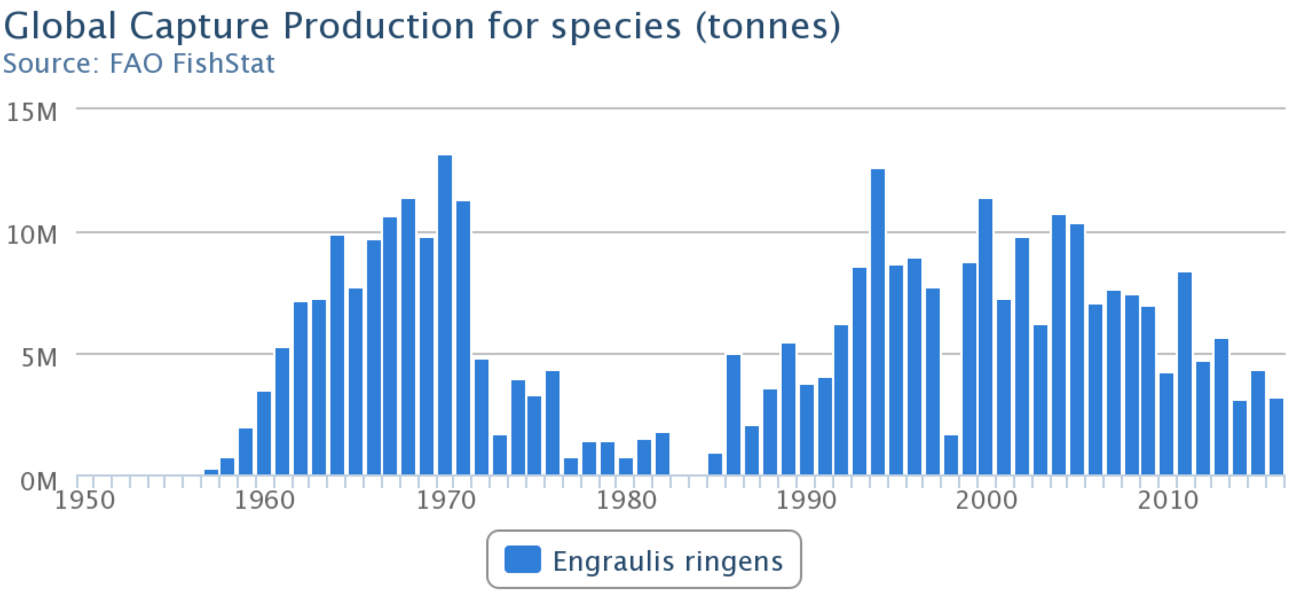
The Peruvian anchoveta

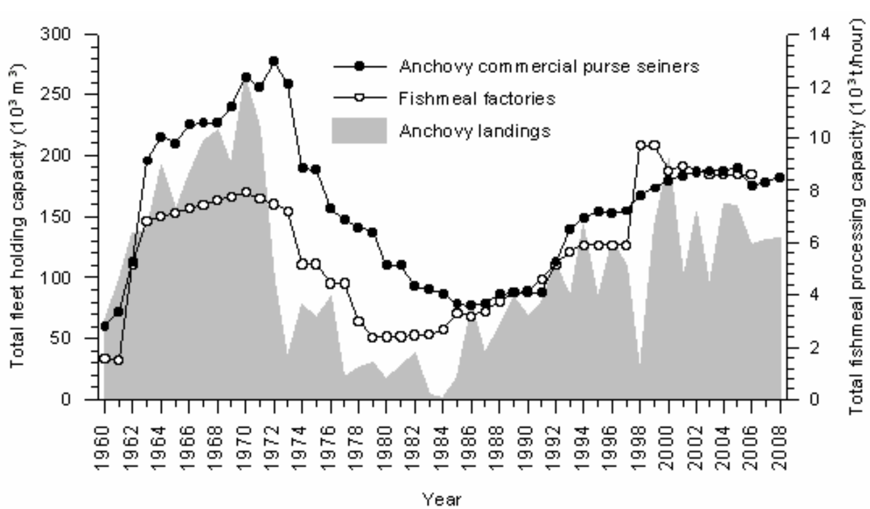
Year	No. of vessels	No. of fishing days	Catch (million tons)
1959	414	294	1.91
1960	667	279	2.93
1961	756	298	4.58
1962	1069	294	6.27
1963	1655	269	6.42
1964	1744	297	8.86
1965	1623	265	7.23
1966	1650	190	8.53
1967	1569	170	9.82
1968	1490	167	10.26
1969	1455	162	8.96
1970	1499	180	12.27
1971	1473	89	10.28
1972	1399	89	4.45
1973	1256	27	1.78
1974	-	-	4.00
1976	-	-	4.30
1977	-	-	0.80
1978	-	42	0.50

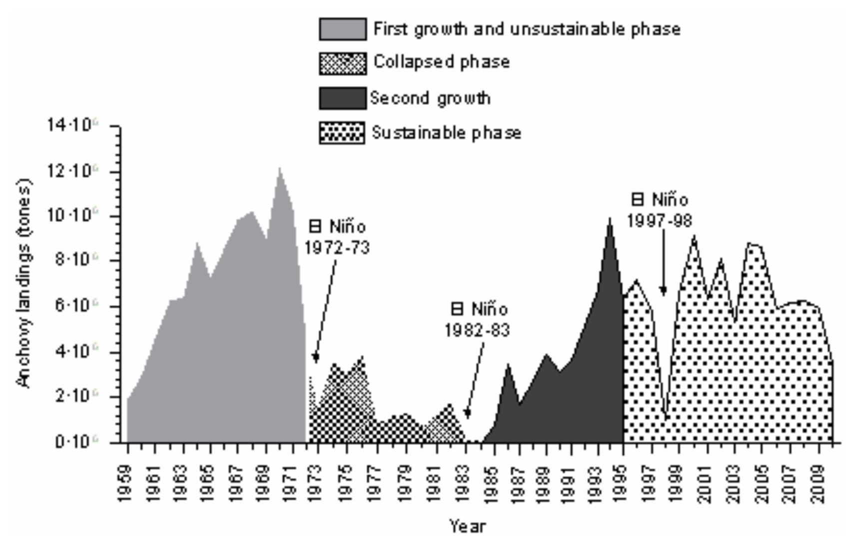




Peruvian anchoveta recent history



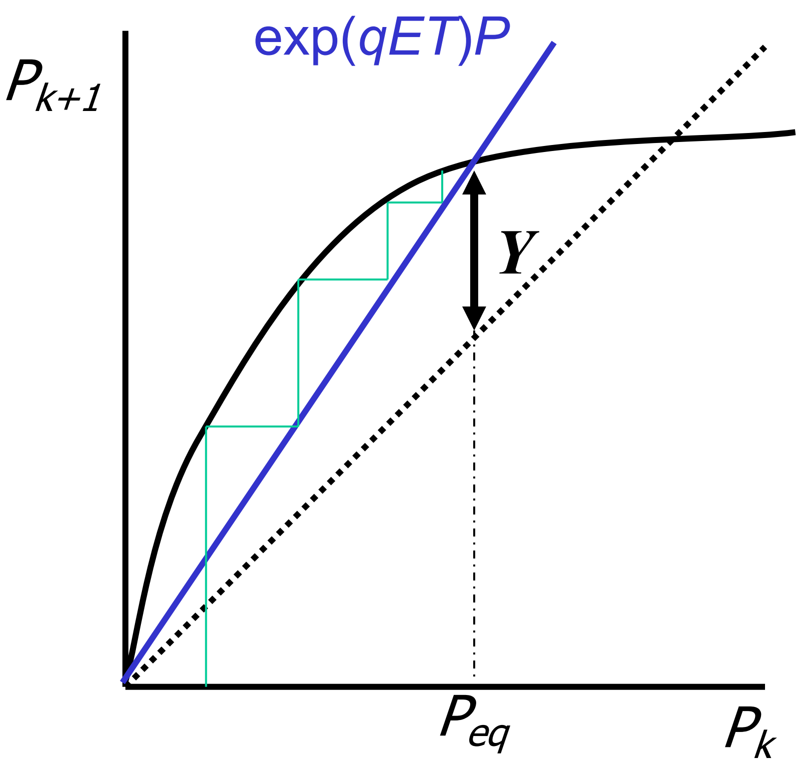




Constant effort policies

If E_k and T_k or their product are kept constant then

$$P_{k+1} = F(P_k) - H_k = F(P_k)\exp(-qET)$$



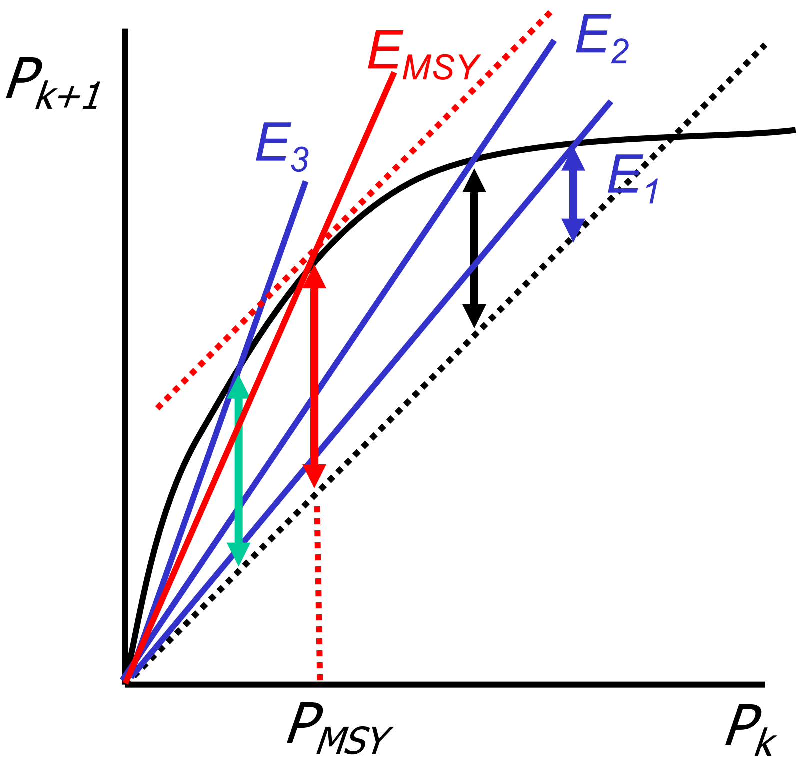
At equilibrium

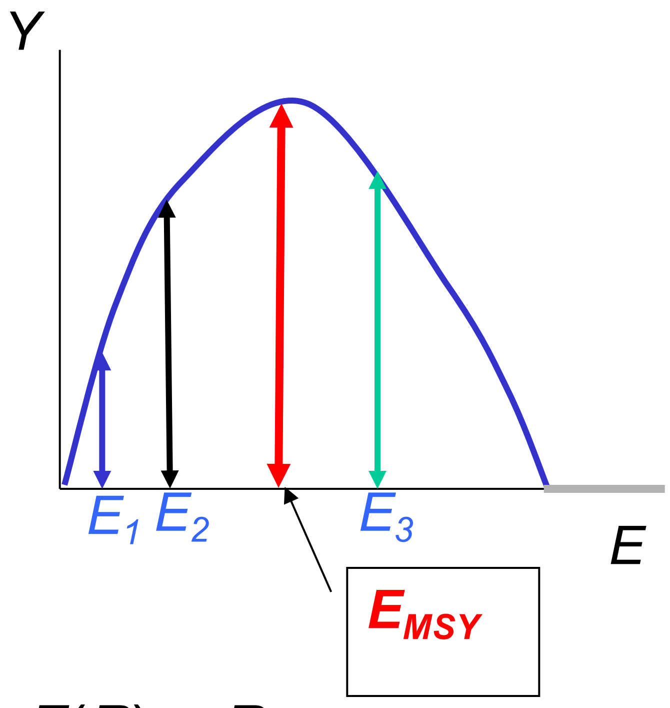
$F(P) = \exp(qET)P$

Sustainable Yield = $F(P) - P =$

$= F(P)\,(1 - \exp(-qET))$

Production curves and MSY





MSY = Max Sustainable Yield = $F(P) - P$

$F'(P_{MSY}) = 1$ $\quad$ $F(P_{MSY}) = \exp(qE_{MSY}T)\, P_{MSY}$

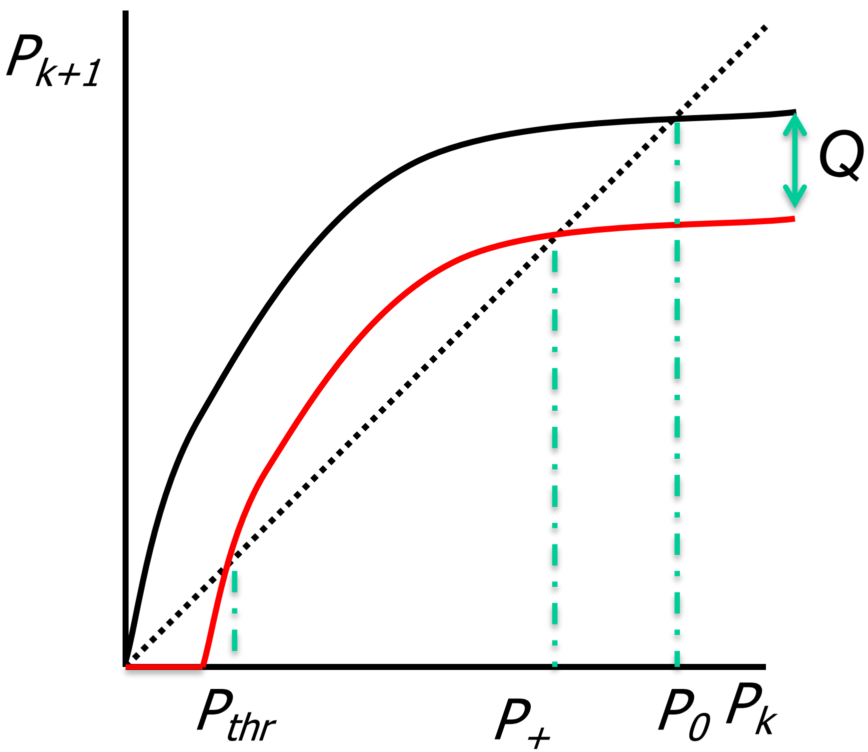
$E_{MSY} = \ln(F(P_{MSY})/P_{MSY})/qT$

Total catch quotas

$$P_{k+1} = F(P_k) - H_k = P_k \Lambda(P_k) - H_k$$

$$H_k = \begin{cases} Q & \text{if } R_k \geq Q \\ R_k & \text{if } R_k < Q \end{cases}$$

Q = quota (e.g., 250 animals hunted)

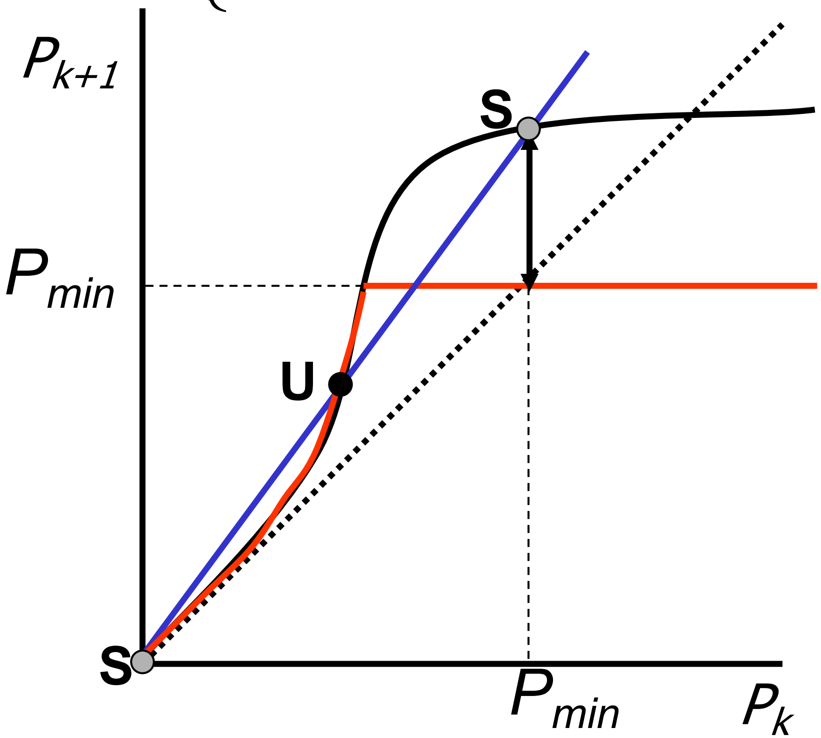


If quota is blindly used under any condition, resource can be driven down to extinction whenever disturbance pushes P below threshold P_{thr}

Constant escapement policies

$$H_k = \begin{cases} 0 & if\ R_k < P_{\min} \\ R_k - P_{\min} & otherwise \end{cases}$$

P_{min} = escapement

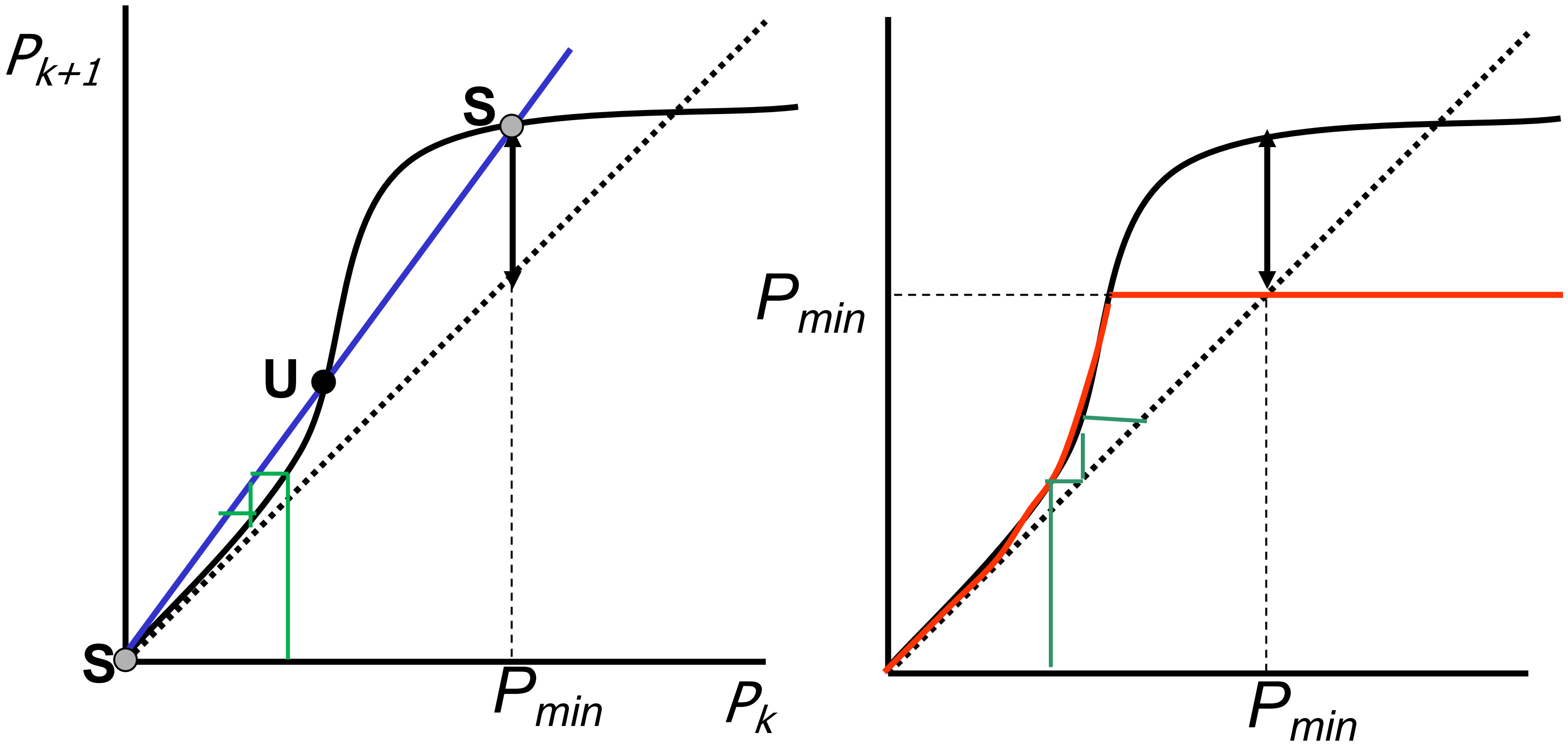


With a constant effort policy there would be instability and risk of extinction

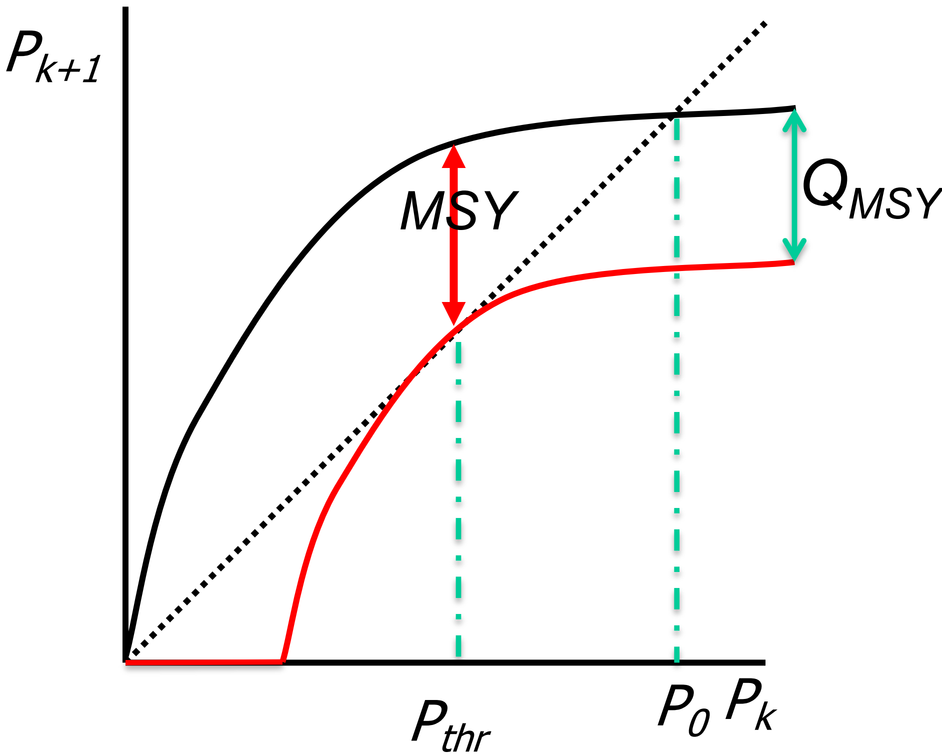
Constant escapement policies

$$H_k = \begin{cases} 0 & if\ R_k < P_{\min} \\ R_k - P_{\min} & otherwise \end{cases}$$

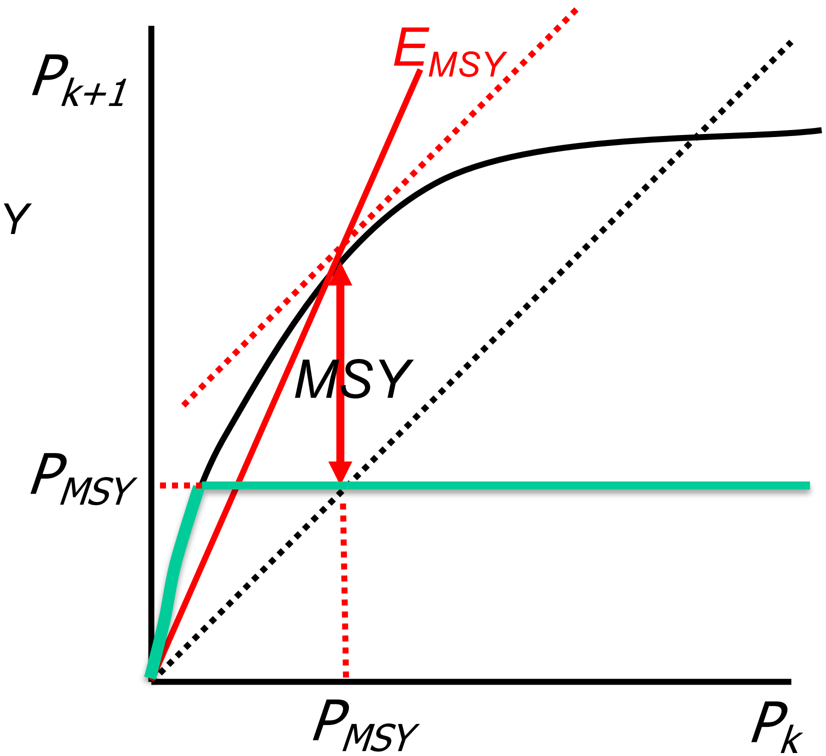
P_{min} = escapement



MSY, quotas, constant effort, constant escapement



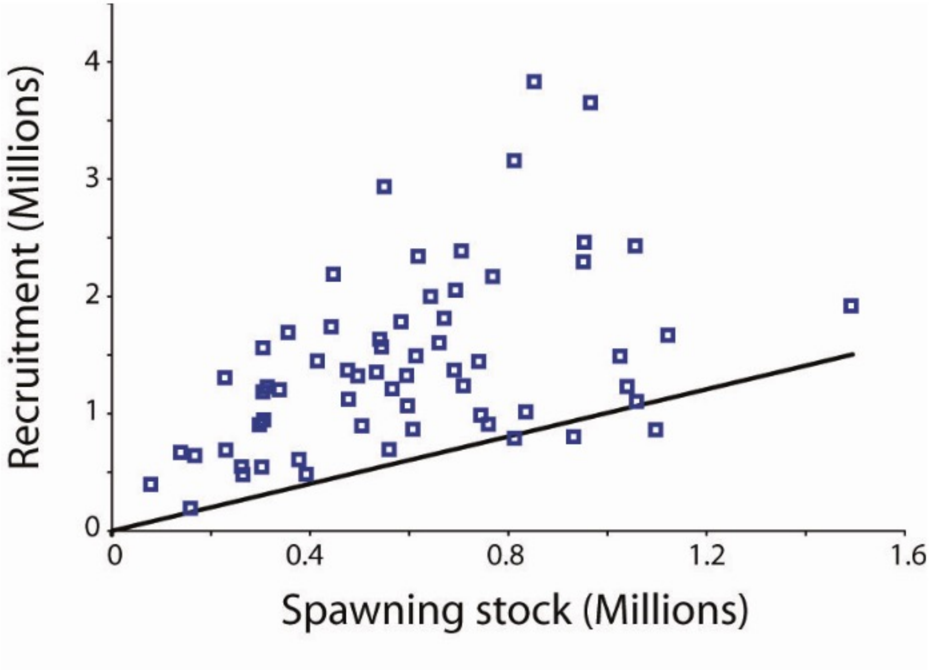
INSTABILITY!



The optimal escapement is P_{MSY}

Including stochasticity

Figure 18: Spawning stocks and corresponding recruitmemts for the sockeye salmon of the Skeena River (British Columbia, Canada) between 1908 and 1970 (after Walters, 1975).



Maximizing Average Harvest

Minimizing Variance

Introducing economics (H.S. Gordon 1954)
Open access – no regulation

H. Scott Gordon

THE ECONOMIC THEORY OF A COMMON-PROPERTY RESOURCE: THE FISHERY[1]

H. SCOTT GORDON
Carleton College, Ottawa, Ontario

I. INTRODUCTION

The chief aim of this paper is to examine the economic theory of natural resource utilization as it pertains to the fishing industry. It will appear, I hope, that most of the problems associated with the words "conservation" or "depletion" or "overexploitation" in the fishery are, in reality, manifestations of the fact that the natural resources of the sea yield no economic rent. Fishery resources are unusual in the fact of their common-property nature; but they are not unique, and similar problems are encountered in other cases of common-property resource industries, such as petroleum production, hunting and trapping, etc. Although the theory presented in the following pages is worked out in terms of the fishing industry, it is, I believe, applicable generally to all cases where natural resources are owned in common and exploited under conditions of individualistic competition.

II. BIOLOGICAL FACTORS AND THEORIES

The great bulk of the research that has been done on the primary production phase of the fishing industry has so far been in the field of biology. Owing to the lack of theoretical economic research,[2] biologists have been forced to extend the scope of their own thought into the economic sphere and in some cases have penetrated quite deeply, despite the lack of the analytical tools of economic theory.[3] Many others, who have paid no specific attention to the economic aspects of the problem have nevertheless recognized that the ultimate question is not the ecology of life in the sea as such, but man's use of these resources for his own (economic) purposes. Dr. Martin D. Burkenroad, for example, began a recent article on fishery management with a section on "Fishery Management as Political Economy," saying that "the Management of fisheries is intended for the benefit of man, not fish; therefore effect of management upon fishstocks cannot be regarded as beneficial *per se*."[4] The

[1] I want to express my indebtedness to the Canadian Department of Fisheries for assistance and co-operation in making this study; also to Professor M. C. Urquhart, of Queen's University, Kingston, Ontario, for mathematical assistance with the last section of the paper and to the Economists' Summer Study Group at Queen's for affording opportunity for research and discussion.

[2] The single exception that I know is G. M. Gerhardsen, "Production Economics in Fisheries," *Revista de economía* (Lisbon), March, 1952.

[3] Especially remarkable efforts in this sense are Robert A. Nesbit, "Fishery Management" ("U.S. Fish and Wildlife Service, Special Scientific Reports," No. 18 [Chicago, 1943]) (mimeographed), and Harden F. Taylor, *Survey of Marine Fisheries of North Carolina* (Chapel Hill, 1951); also R. J. H. Beverton, "Some Observations on the Principles of Fishery Regulation," *Journal du conseil permanent international pour l'exploration de la mer* (Copenhagen), Vol. XIX, No. 1 (May, 1953); and M. D. Burkenroad, "Some Principles of Marine Fishery Biology," *Publications of the Institute of Marine Science* (University of Texas), Vol. II, No. 1 (September, 1951).

[4] "Theory and Practice of Marine Fishery Management," *Journal du conseil permanent international pour l'exploration de la mer*, Vol. XVIII, No. 3 (January, 1953).

The Journal of Political Economy, Vol. 62, No. 2 (Apr., 1954), pp. 124-142

Collapse: Is there an economic reason?

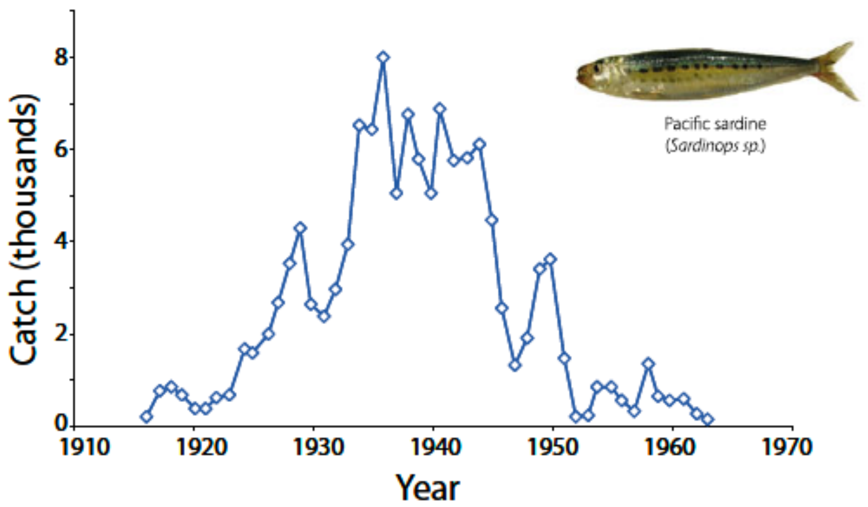


Fig. 8.21 Yearly sardine (*Sardinops caerulea*) catches along the Pacific shores of North America. Data after Murphy (1966)

Introduce selling prices of harvested resource and costs of effort

p= price of unit biomass harvested

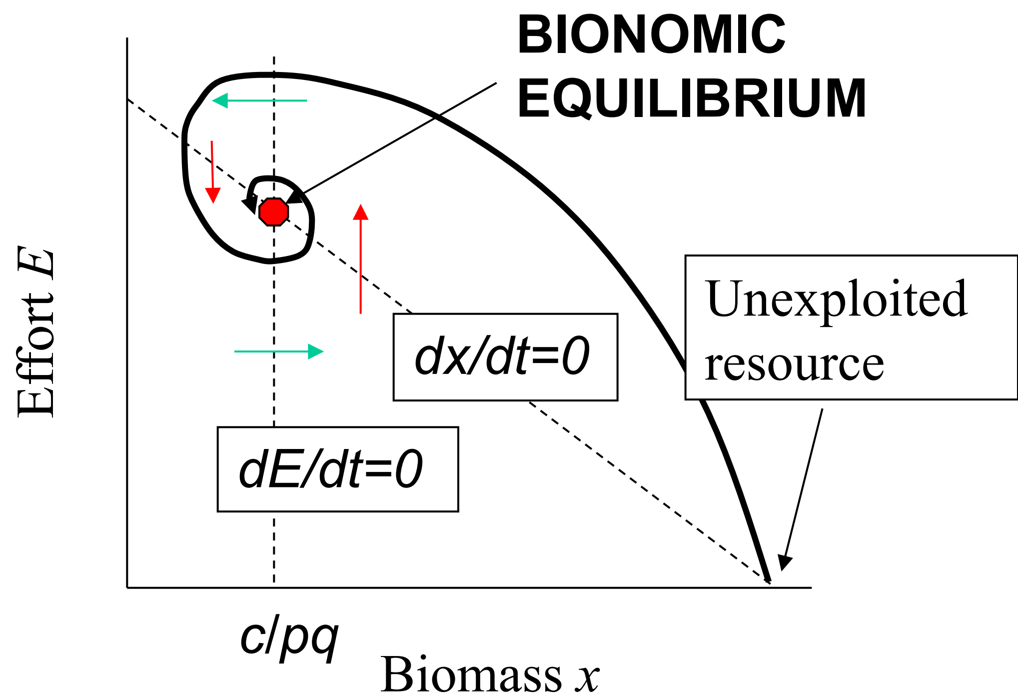
c = cost of unit effort

Introducing economics (H.S. Gordon 1954) Open access – no regulation

$dx/dt = F(x) - qEx$

$dE/dt = k(pqEx - cE)$

p= price of unit biomass
c = cost of unit effort
pqEx – cE = total profit
k = sensitivity to profit

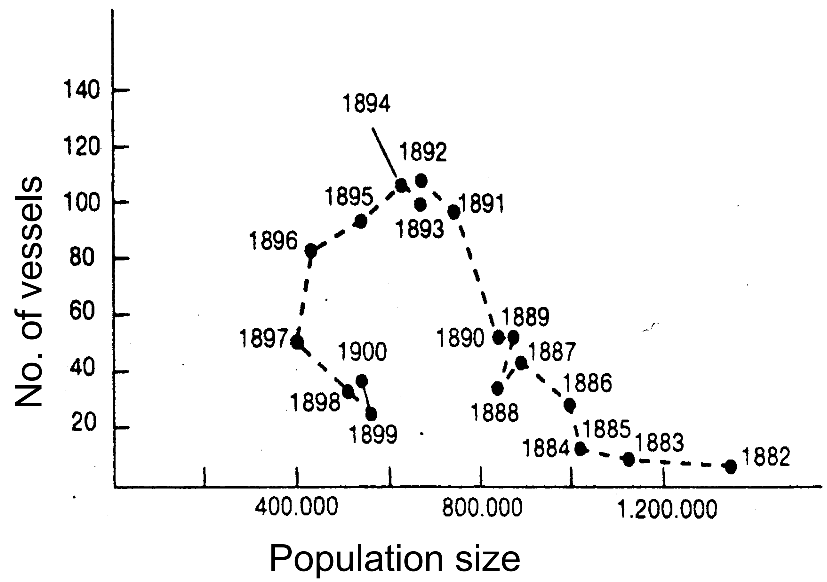


Lotka-Volterra-type model (assume constancy of *p* and *c*)

Periods of overcapitalization and strong overexploitation

The Northern fur seal (*Callorhinus ursinus*)

The exploitation of fur seal in North Pacific between 1882-1900

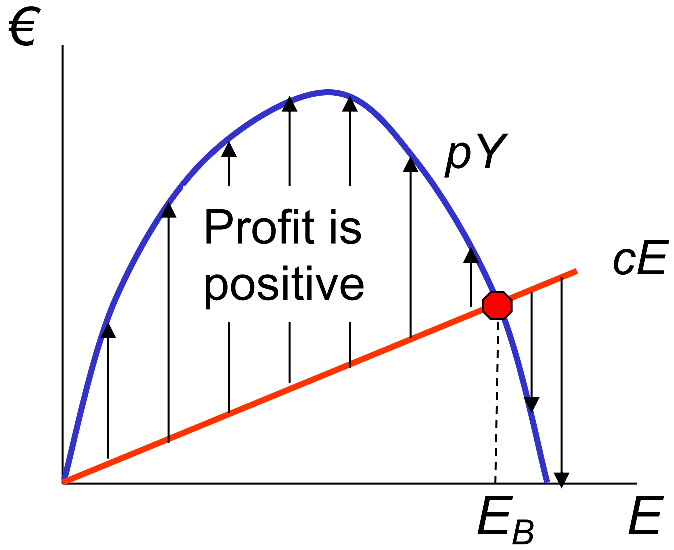


Open access: Gordon's static analysis

Total sustainable revenue $TR = pY = pqEx_{eq}$

Total cost $TC = cE$

Total sustainable profit $TP = pY - cE = (pqx_{eq} - c)E$



An open access resource will converge to the bionomic equilibrium at which $TP = 0$

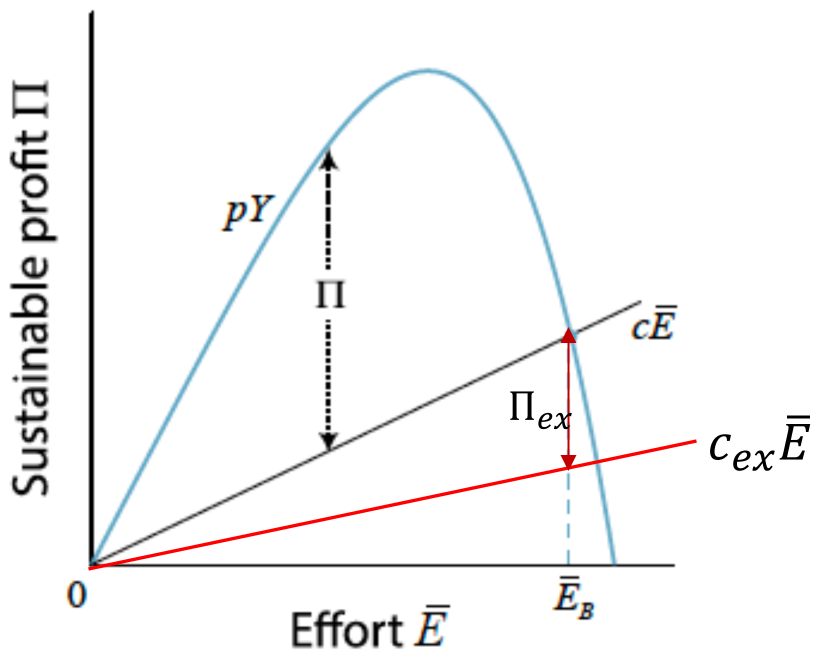
- Effort E_B is > E_{MSY}
- Total profit (net benefit to society) is dissipated
- Resource biomass $x_{eq} = c/pq$ is not related to biology

H.S. Gordon, 1954. The Economic Theory of a Common-Property Resource: The Fishery. The Journal of Political Economy, 62: 124-142.

The opportunity cost

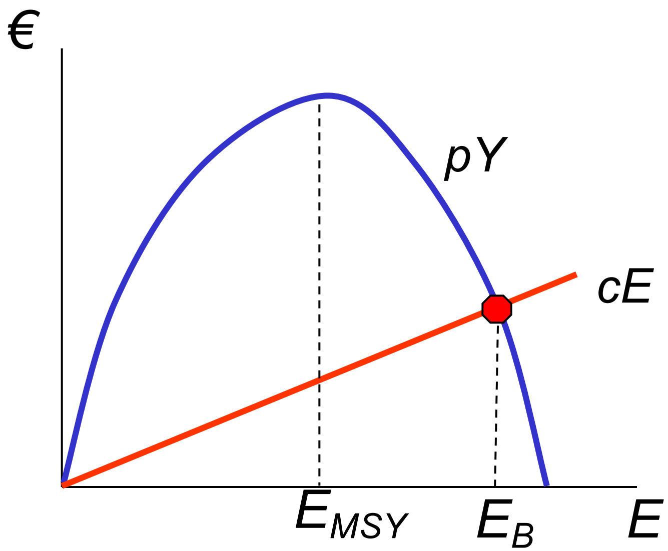
The **opportunity cost** of a particular activity is the explicit cost plus the benefit given up by engaging in that activity, relative to engaging in the most profitable alternative activity.

$c = c_{ex} + c_{al}$

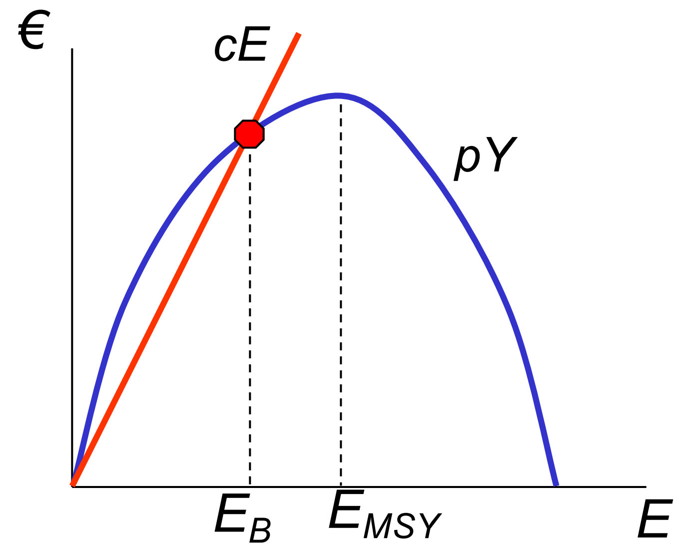


Π_{ex} is the net benefit accruing to the pockets of exploiters.
It might also be obtained by entertaining the most profitable economic activity.
No benefit is added to society by starting the activity related to the exploitation of the resource.

The role of the opportunity cost *c*



Low cost: resource is overexploited



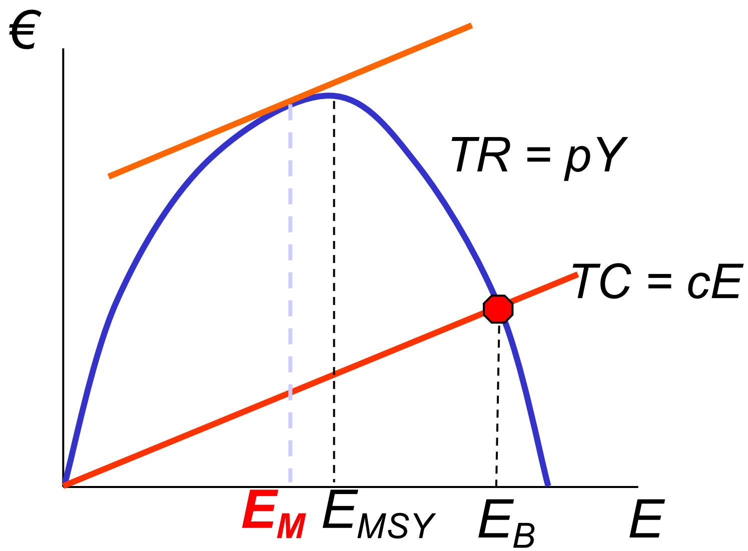
High cost: resource is underexploited

High costs of effort are unrealistic

•Commercial fishing and hunting and natural forests exploitation are typical of developing countries

•Cost *c* is an opportunity cost

Economic and ecological efficiency



At E_M the net benefit to the society $TP = TR - TC$ is maximized

$dTP/dE = 0$ namely

$dTR/dE = dTC/dE = c$

Marginal revenue = marginal cost

Regulatory methods should be introduced to decrease effort thus generating positive economic benefits to the society and reducing the risk of extinction.

Two problems: (1) transient, (2) discounting

The case of logistic growth

Total sustainable profit $TP = pY - cE = pqEx_{eq} - cE$

At biological equilibrium $F(x_{eq}) = qEx_{eq}$ = harvest rate

$$dx/dt = rx(1\text{-}x/K) - qEx$$

$$x_{eq}=K(1 - qE/r)$$

$TP = pqEx_{eq} - cE = pqKE(1 - qE/r) - cE$

At bionomic equilibrium $TP = 0 \rightarrow pqK\,(1 - qE/r) - c = 0$

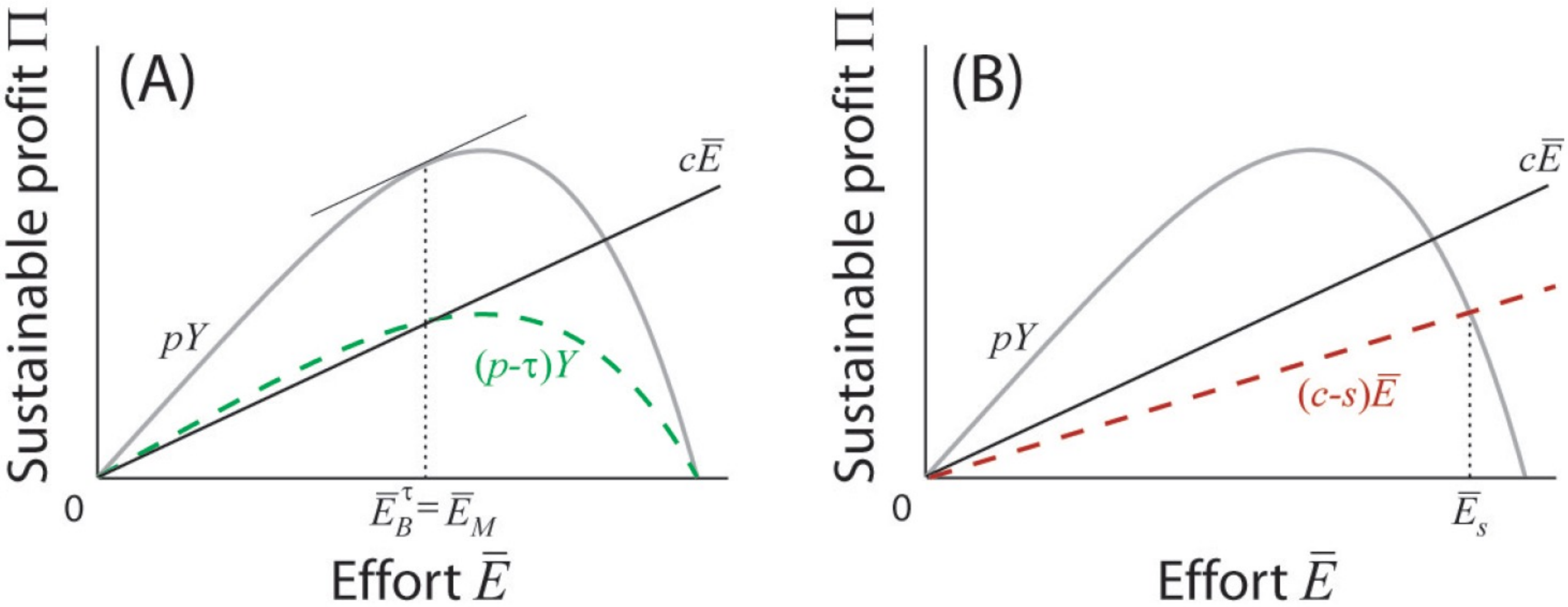
$x_B = c/pq \qquad E_B =(r/q)(1 - (c/(pqK))$

To maximize total profit TP we find E_M such that dTP/dE=0

$dTP/dE=pqK - 2pq^2KE/r - c \;\rightarrow E_M = (r/2q)(1 - (c/(pqK))$

$$E_M = E_B/2$$

The effect of taxes and subsidies



Tax the unit biomass that is harvested

Total profit = $pY - cE - \tau Y = 0$

Benefit to society = τY