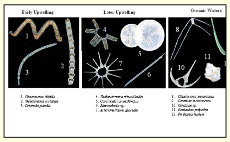
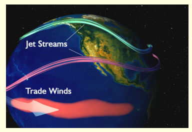




Marine Productivity and the Fishery Crisis-I

Marine Productivity and ENSO

MES-ESS Winter 2011
January 18

- Comments: Systems Thinking, Models, Science
- Marine productivity models
  - Distribution and magnitude
  - Limits and controls
- Fisheries mis-management and crisis
  - Case Study. El Niño (ENSO) and the anchoveta fishery
  - Food from the Sea
  - Causes and consequences of over fishing
  - Solutions

POPULAR REVIEW SCIENTIFIC AMERICAN

Pauly and Watson (2003). Counting the last fish. *Scientific American.* July. V289:42-47

ECOL CONSEQUENCES OF INDUSTRIALIZED FISHERIES – FOCUSED PAPER

Myers and Worm (2003). Rapid worldwide depletion of predatory fish communities. *Nature.* 423: 280-283

DATA GAPS – FOCUSED PAPER

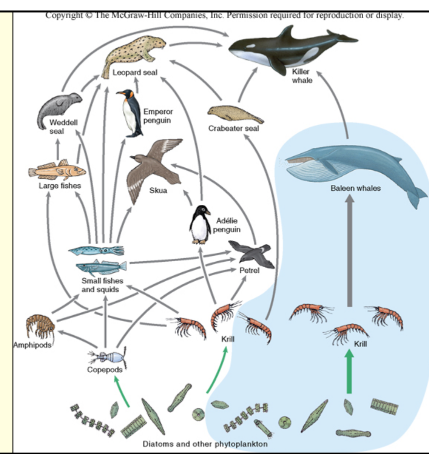
Watson, R. and D. Pauly. (2001). Systematic distortion in world fisheries catch trends. *Nature.* 414: 534-536

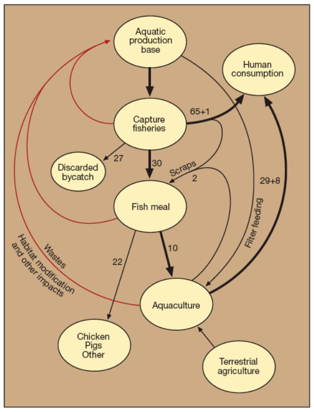
SOLUTIONS – INSIGHT PAPER

Pauly, D. et al. (2002). Towards Sustainability in World Fisheries. *Nature.* 418:689-695

SOLUTIONS – REVIEW PAPER

Rosamond L. et al. (2000). Effect of Aquaculture on World Fish Supplies. *Nature.* 405: 1017-1024

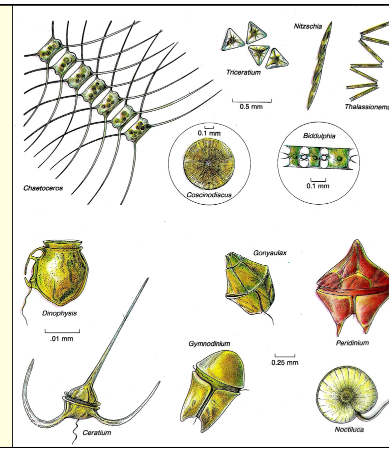




Model showing flow of biomass from primary production to fisheries.

To properly manage fisheries it is necessary to estimate the global primary production and its variation over time.

From Naylor et al. 2000



Biomass and Productivity

- Biomass. Amount of living material at any one time (standing crop or stock). Expressed in units of carbon per unit area or volume (e.g. g of C/m ^{2})
- Productivity. Rate of biomass production. Expressed in same units as biomass but per unit time (e.g. g of C/m ^{2}/year). Primary productivity refers to the production of organic matter from inorganic carbon by plants, algae and bacteria. Photosynthesis is one of the metabolic process (chemosynthesis is another) associated with primary production.
  - Gross production is the total carbon fixed and net is gross minus respiration.

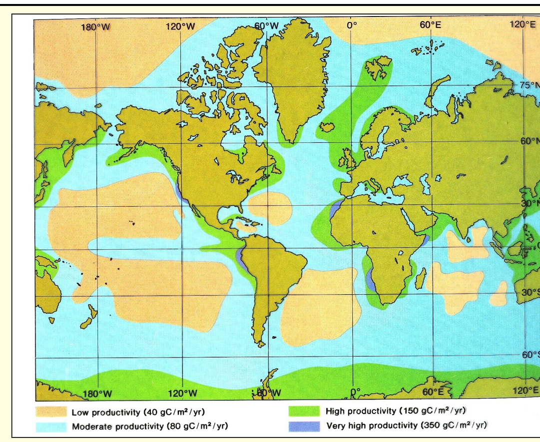


Table 10.1 Typical Rates of Primary Production in Various Marine Environments

Environment	Rate of Production (Grams of Carbon Fixed/M^2/YR)
PELAGIC ENVIRONMENTS	
Arctic Ocean	<1–100
Southern Ocean (Antarctica)	40–260
Subpolar seas	50–110
Temperate seas (oceanic)	70–180
Temperate seas (coastal)	110–220
Central ocean gyres*	4–40
Equatorial upwelling areas*	70–180
Coastal upwelling areas*	110–370
BENTHIC ENVIRONMENTS	
Salt marshes	250–2,000
Mangrove forests	370–450
Seagrass beds	550–1,100
Kelp beds	640–1,800
Coral reefs	1,500–3,700
TERRESTRIAL ENVIRONMENTS	
Extreme deserts	0–4
Temperate farmlands	550–700
Tropical rain forests	460–1,600

Note: Production rates can be much higher at certain times or in specific locations, especially at high latitudes. Values for some selected terrestrial environments are given for comparison.

*See "Patterns of Production," p. •••.

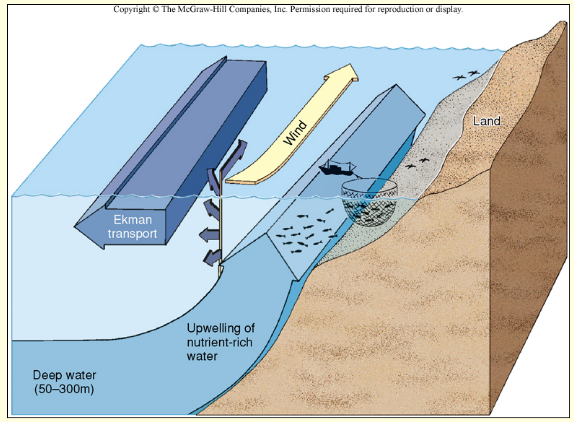


TABLE 7.1
Distribution of Elements in Organism (N) and Seawater (A) — A Measure of Availability to Need

Element	N (g/100 g)	A (g/m³)	A/N
H	7 g		
Na	3	10.75 kg	3600
K	1	390 g	390
Mg	0.4	1.3 kg	300
Ca	0.5	416 g	830
C	30	28 g	1
Si[a]	0.5	500 mg	1
Si[b]	10	500 mg	0.05
N	5	300 mg	0.06
P	0.6	30 mg	0.05
O (O_2 + CO_2)	47	90 g	2
S	1	900 g	900
Cl	4	19.3 kg	4800
Cu	5 mg	10 mg	2
Zn	20 mg	5 mg	4
B	2 mg	5 mg	2500
V	3 mg	0.3 mg	0.1
As	0.1 mg	15 mg	150
Mn	2 mg	5 mg	2.5
F	1	1.4 g	1400
Br	2.5 mg	66 g	26000
Fe[a]	1 mg	50 mg	0.05
Fe[b]	40 mg	50 mg	1.3
Co	0.05 mg	0.1 mg	2
Al	1	120 mg	120
Ti	100 mg	—	—

[a] Phytoplankton.
[b] Diatoms.

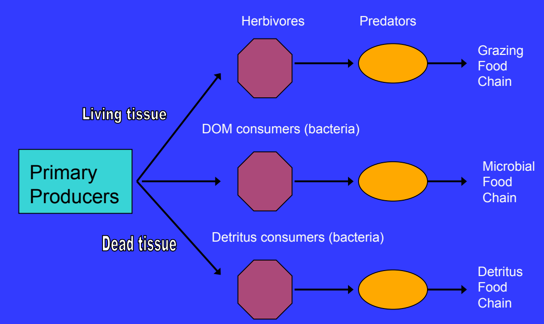
Liebig's Law of the Minimum
The nutrient that is available (A) in the least concentration relative to need (N) will be the limiting nutrient for growth. This can be computed by using the ratio A/N. The element with the lowest ratio is the limiting one.

Redfield's Ratio
The average ratio of C:N:P in marine phytoplankton. Molar ratio is 106C:16N:P
By weight the ratio is, 41C:7N:1P

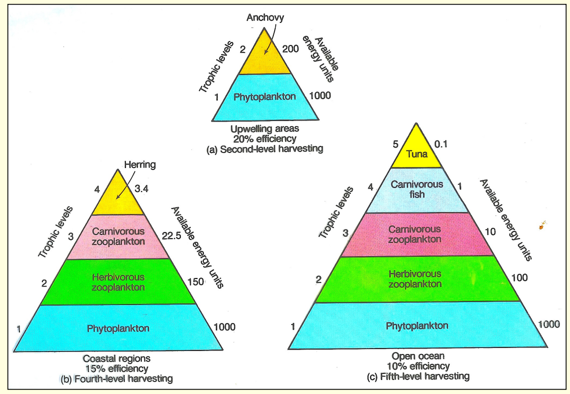
Table from Millero&Sohn (1992), Chemical Oceanography)

Why is the Coastal Zone so Productive?

- Abundant supply of inorganic nutrients (N, P)
  - Weathering of continental masses (wind and water)
  - Coastal wind-driven upwelling
  - Other upwelling: tidal, bathymetric, river-driven and internal waves
  - Recycling in the shallow water column and in shallow sediments
- Abundant light in the water column and sea floor
  - Chemical and physical processes remove suspended sediments
- Elevated biomass and production of alga and plants
  - Phytoplankton, macroalgae, seagrasses, marsh plants
- Grazing, detrital and DOM pathways for fixed C
- Short and efficient food chains
- Estuaries have few but highly productive species
- Estuaries can have two-layered circulation that retains nutrients and organisms



Three pathways over which primary production flows up the food chain



From Duxbury&Duxbury. An Introduction to the World's Oceans

Table 11.2 DIVISION OF THE OCEANS INTO PROVINCES BASED ON LEVEL OF PRIMARY PRODUCTIVITY

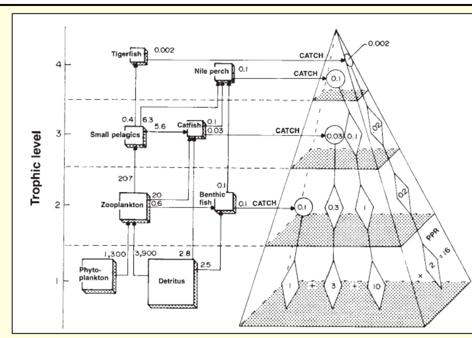
Province	Percentage of the ocean	Area (km^2)	Mean productivity (grams of carbon per m^2 per year)	Total productivity (10^9 tons of carbon per year)
Open ocean	90.0	326×10^6	50	16.3
Coastal zone	9.9	36×10^6	100	3.6
Upwelling areas	0.1	3.6×10^5	300	0.1
Total				20.0

Source: After Ryther, 1969.

Table 11.3 ESTIMATED TOTAL FISH PRODUCTION OF THE WORLD'S OCEANS BASED ON THE THREE PROVINCES OF TABLE 11.2

Province	Primary production (tons of organic carbon)	Trophic levels	Efficiency (%)	Fish production (tons, fresh weight)
Oceanic	16.3×10^9	5	10	16×10^5
Coastal	3.6×10^9	3	15	12×10^7
Upwelling	0.1×10^9	1½	20	12×10^7
Total				24×10^7

Source: After Ryther, 1969.



Model used to estimate primary production rate (PPR) to sustain fish catches. The left section shows stock and flows (pools and fluxes) in tons. The right section reflects the trophic level associated with each stock. A 10% efficiency of transfer is used to estimate PPR.
From: Pauly&Christensen (1995)

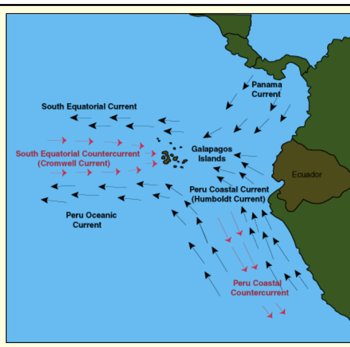
Rise and Fall of Anchoveta Fishery in Peru

- Peruvian anchoveta fishery
- El Niño phenomena off the coast of Peru
- The Southern Oscillation and ENSO
  - SOI index
  - Modern monitoring
  - ENSO and global climate
- Biological consequences

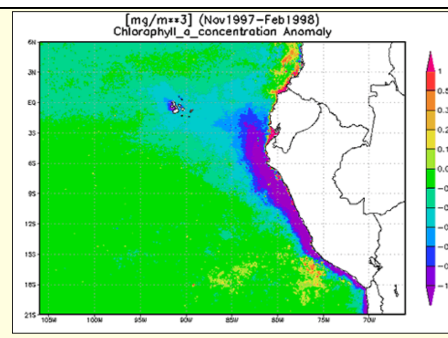
- Implications for fisheries management

-Peruvian Anchoveta (*Engraulis ringens*)
-Filter feeder mostly on phytoplankton
-Fast growing (Up to 20 cm in 3y), spawn August
-Used primarily to produce oil and fish meal to supplement animal feed

http://www.fishbase.org/Summary/SpeciesSummary.php?id=4 and http://animaldiversity.ummz.umich.edu/site/resources/Grzimek_fish/Clupeiformes/Engraulis_ringens.jpg/badge.jpg

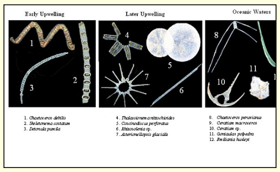


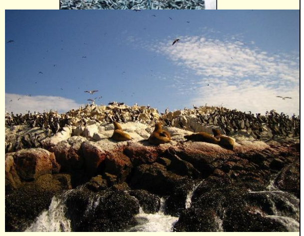
Surface circulation pattern in eastern equatorial Pacific. Cool water flowing from the south and upwelling keep the climate in this region cool. The Andes intercept the humidity traveling from the west resulting in dry conditions. From: http://www.geol.umd.edu/~jmerck/galsite/research/projects/fitz/currents.gif



Upwelling results in high concentrations of inorganic nutrients and phytoplankton productivity.

From http://daac.gsfc.nasa.gov/oceancolor/locus/images/elnino_anomaly_Nov97Feb98.gif

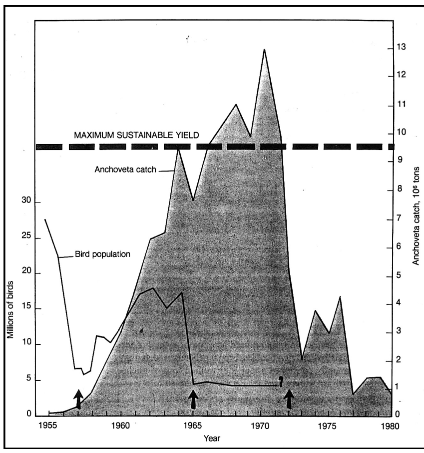




www.scielo.cl/fbpe/img/gayana/v67n2/f3tarazz.jpg
www.imarpe.gob.pe/estadistica/estadis2.html, http://www.travelblog.org/South-America/Peru/Pisco/blog-44721.html

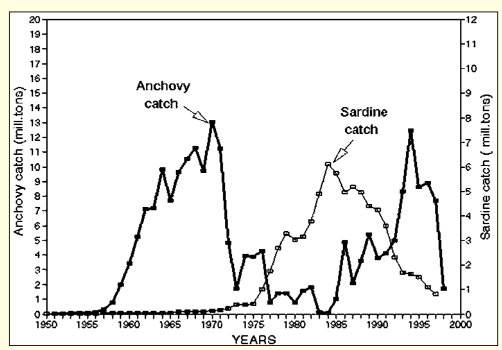
Maximum Sustainable Yield (MSY): The largest average catch or yield that can continuously be taken from a stock under existing environmental conditions.

(For species with fluctuating recruitment, the maximum might be obtained by taking fewer fish in some years than in others.) Also called: maximum equilibrium catch ; maximum sustained yield; sustainable catch. From. www.nefsc.noaa.gov



Peruvian Anchovy Catches, Bird Populations, MSY and El Niño.

- -Rapid growth of fishery in 60s
- -MSY = 9.5 MT
- -Overshoot due to overcapitalization of fishery, new technology and dependency of Peru on Fishery (1/3 of economy)
- -In 1971 catches = 22% of world catch
- -Bird populations declines as fishery grows and El Niño events occur
- -El Niño events + overfish = collapse

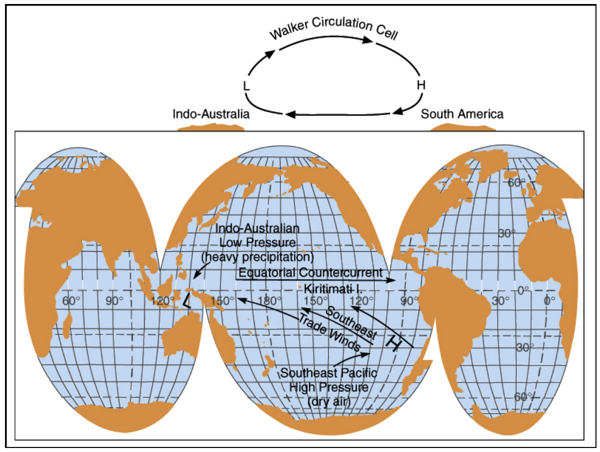


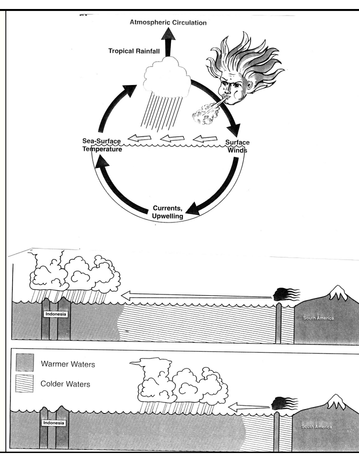
Collapse and recovery of Peruvian anchoveta. Why do sardine catches increase when anchovy catches are low?

From : http://www.fao.org/docrep/005/y2787e/y2787e3b.gif

El Niño off the coast of Peru

- Annual occurrence starting in Dec and lasting ~ 3 months. Frequency of severe events is ~ 5-7 y and events may last 2 y.
- Weakening of coastal winds and upwelling
- Low concentrations of inorganic nutrients
- Low primary production
- Warming of sea surface
- Decline of native fishes and birds and appearance of tropical species
- Torrential rains





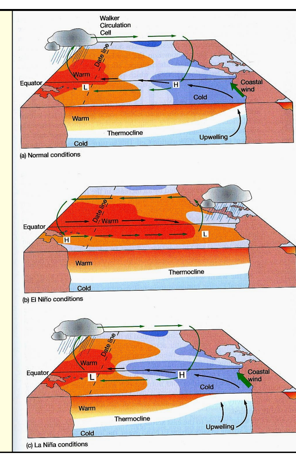
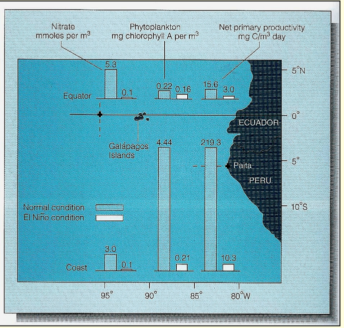


Figure 15.14 Effect of El Niño conditions on surface nutrient content, amount of phytoplankton, and phytoplankton productivity offshore at the equator and near the Peruvian coast. Equator: normal values from April 1982, El Niño values from March 1983. Coast: normal values from July 1983, El Niño values from May 1983. (The figures are averages for measurements taken along the tracks or transects shown as ---- through the sites marked +. Values very near shore on the coastal transect were some three to four times higher than the whole-transect average due to the weak residual cool upwelling lingering there.)



Data from Barber and Chavez (1983) Biological consequences of El Niño. Science: 222:1203-1210. Summary figure by Milne (1995). Marine Life and the Sea.

are the iguana's preferred food. Instead, these types of algae are replaced by brown algae, which are harder for the iguanas to digest. Unlike many marine animals that can migrate to other areas where food supplies are plentiful,

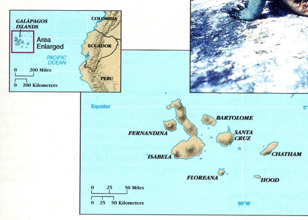


FIGURE 7D Marine iguana and location maps of the Galápagos Islands.

Marine iguanas (*Amblyrhynchus cristatus*) populations can decrease by 90% during an ENSO year (decrease food and changing composition of algae). During ENSO years their biomass decreases by 20% (half of loss from cartilage and connective tissue).