Fisheries Management with Uncertainty

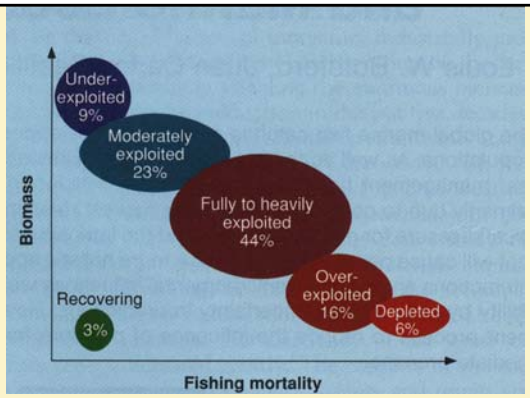
- Context
- The Overharvest Problem
- Potential for "Recovery"
- Management for MSY
- Proposed Solutions
- Marine Reserves can increase yield

Importance of Marine Fisheries

- Immense social and economic value
- Direct employment ≈ 200 million people
- Human diet: fisheries ≈ 1/5 animal protein
- Revenues: ≈ $70 billion direct
  - untold indirect revenues

Signs of Overharvest

- Global catch at upper limit
  ≈ 100 million tons, early 1990's
- 2/3 stocks fully or over-exploited
- Indirect impacts
  - non-target species (bycatch)
  - marine habitats



Botsford, L.W. et al. 1997. *Science* 277:509-515.

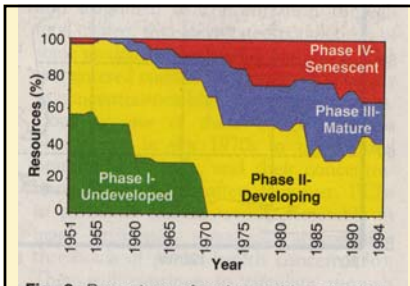
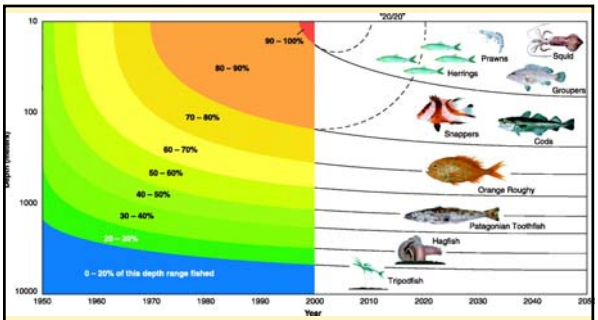


Fig. 3. Percentage of major world marine fish resources in different phases of development, 1951 to 1994 [from (*57*)]. Undeveloped = a low and relatively constant level of catches; developing = rapidly increasing catches; mature = a high and plateauing level of catches; senescent = catches declining from higher levels.

Vitousek et al. 1997. *Science* 277:494-499



Fraction of world fisheries vs. depth: 1950-2000 & 2050 projection. Note: 20% protection from fishing to 100m depth by 2020 requires strong reversal of trends.

Pauly D, et al. 2003. *Science* 302:1359-1361.

Large fishes depleted

- 13 regions: 4 continental shelves, 9 oceanic
- Biomass large marine spp 10% pre-industrial levels
  (e.g., cod, halibut, tuna, swordfish, marlin)
- Industrial fisheries: biomass ↓80% w/in 15 yr
- "Missing baselines" -- historical perspective needed (recent data misleading)
- "We are really too good at killing these [fish].
  -- Boris Worm

Myers, RA, Worm, B. 2003. *Nature* 423:280-283.

Conclusion:
fisheries management not been sustainable
(sustainability is a main goal)

Primary Reasons:
- sociopolitical pressure to ↑ harvest
- intrinsic uncertainty in harvest limit predictions

3 General Solutions:
1. Improve predictions (↓ uncertainty)
   - interspecific interactions
   - physical environmental influences
2. Alter management process
   ↓ influence of pressure for greater harvest
3. No-take Reserves

The Ratchet Effect

1. "Stable" periods:
   harvest rates @ bioeconomic steady-state
   (often ecologically excessive)
2. "Good" years: additional investment
3. Decrease to ≤ "normal" stock sizes:
   industry appeals to government for help
4. Response: subsidies (direct or indirect)
   effect: encourage overharvesting
5. Ratchet effect:
   – no limit on harvest investment during high stocks
   – pressure not to disinvest during low stocks

Reasons for Ratchet Effect:
1. Little pressure for lower harvest rates
2. Managers must prove harm

Result of Ratchet Effect:
continuous increase in fishing effort;
eventual fishery collapse

Long-term Outcome:
subsidized fishing industry that overharvests

Ludwig et al. 1993. *Science* 260:17,36

Red Snapper politics on Gulf coast

Potential for "Recovery"

Depensation
Meyers et al. 1995. *Science* 269:1106-1108

Management for MSY

- MSY: maximum harvestable indefinitely, without damaging system
- MSY and stock-recruitment curves
- Command and Control Management
  – determine target stock size
  – reduce harvest quotas when N < target
  – increase quotas when N > target
  – policy implementation must be rapid & accurate
- Problems with MSY
  – Conceptual
  – Practical
  – Theoretical

Management for Persistence

"Insurance" value of reduced harvest.

Roughgarden & Smith 1996. *Proc.Nat.Acad.Sci*. 93:5078-5083

"All in all, managing a fishery for the economically optimal target stock is worse than keeping a marble on top of a dome —– it is, in fact, like keeping a marble on top of a dome fastened to the deck of a rolling ship seen through salt-sprayed goggles."

Roughgarden & Smith 1996. *Proc.Nat.Acad.Sci*. 93:5078-5083

Additional Concerns

- Slowly growing populations:
  - liquidate and reinvest profits
- Highly stochastic populations
  - increased risk of overharvest / extinction
  - very different harvest strategy

Proposed Solutions

1. Improve predictions (↓ uncertainty)
   - interspecific interactions
   - physical environmental influences
   - e.g., Jarre-Teichmann 1998. *Ecol.Appl*.8(1)S93-S103 (mass balance trophic models for upwelling systems)
2. Alter management process
   ↓ influence of pressure for greater harvest
3. No-take Reserves

Marine Reserves

- Global
  > 100 reserves in 23 nations
  ~ 1% ocean area
- National
  - National System of Marine Protected Areas (Presidential executive order 5/26/2000)
  - 12 National Marine Sanctuaries

  < 1% US marine area

  e.g., CA: 11 reserves (< 0.02% marine area)

  c.f. Australia, New Zealand

  in progress: 175 mi^2 reserve network (Channel Islands)
- Puget Sound
  - 7 reserves

Reserves Produce Equivalent Yield

Hastings & Botsford 1999. *Science* 284:1537-1538

- Assumptions:
  - adults stationary
  - larvae disperse widely
  - all density dependence at settlement
- 2 Scenarios:

  (1) complete harvest outside reserves (no reproduction)

  (2) mixed strategy: reserves + managed harvest

Traditional Harvest Model

$$n_{t+1} = (1-H)[f(mn_{t-j}) + an_t]$$

n_t = density of adults in reserves, year t
m = # settling juveniles / adult
j = age at maturity
a = annual adult survival
H = fraction harvested
f = density dependence function

Equil: $n = (1-H)[f(mn) + an]$

MSY: $Y_h = \max\{[f(mn) + an] - n\}$
(maximize over n)

Reserve Model

$$n^r_{t+1} = f(cmn^r_{t-j}) + an^r_t$$

n^r_t = density of adults in reserves, year t
m = # settling juveniles / adult
j = age at maturity
a = annual adult survival
f = density dependence function
c = fraction of coastline in reserves

Equil: $n^r = f(cmn^r) + an^r$

MSY: $Y_r = \max[(1-c) f(cmn^r_t)]$
(maximize over c)

Equivalent Yields

change of variables: $u = cn^r$
$p = 1-c$

MSY: $Y_r = \max[pf(mu)]$

Equil: $u = (1-p) f(mu) + au$

$$Y_r = \max\{f(mu) + au] - u\}$$

Harvest model:

$$Y_h = \max\{[f(mn) + an] - n\}$$

Same result for mixed harvest/reserve strategy.

Optimal Reserve Size

$$c = (1-H) - H\left[\frac{an}{f(mn)}\right]$$

where: n = adult density at MSY

Implication:

at MSY, c < H
(reserves are more efficient)

Implications

- Reserve strategy produces greater yield
  - optimal % reserves < optimal % escapement
- Reserves allow for uncertainty
  - reduced risk of overfishing

Are Reserves Effective?

- Population densities: ≈2x greater
- Biomass: ≈3x greater
- Organism size (mean): 20%-30% larger
- Spp diversity: 20%-30% higher

means: inside reserves vs. before reserve creation
(N=89) or similar sites outside reserves

Halpern, BS 2003. 2003. *Ecol. Appl.* 13(1) Suppl. S117-S137.

Evidence of Reserve Effects

- St. Lucia (Caribbean)
  - 5-year reserve network
  - ↑ 46%-90% catches in adjacent areas
- Florida (Cape Canaveral)
  - Merritt Island National Wildlife Refuge
  - 40 km^2, est. 1962
  - abundance: ↑2.3x-12.8x
  - larger/older fish: most world-record catches adjacent

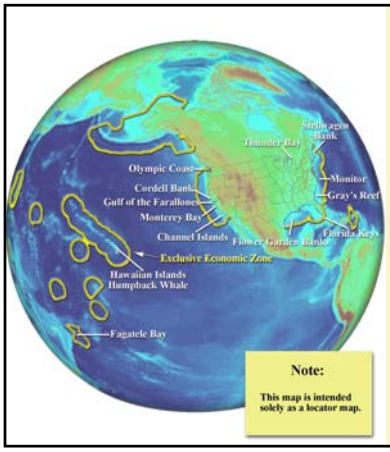
Conclusion:

Reserve spillover can support fisheries

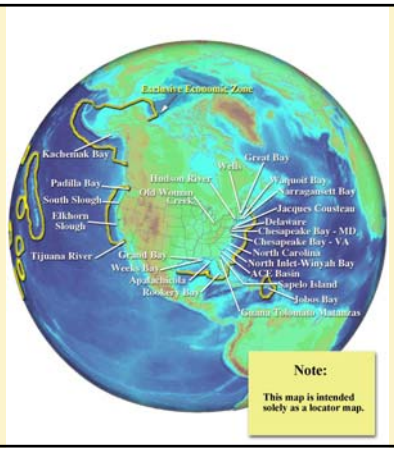
Roberts *et al*. 2001. *Science* 294:1920-1923. (30 Nov. 2001)

Marine Protected Areas in U.S.

http://www.mpa.gov



National Marine Sanctuaries



National Estuarine Research Reserves

Principles of Reserve Design

1. Reserves ≅ ↑ lower harvest size(age) limit
2. Reserves ≅ ↓ fishing mortality
3. Reserves for biodiversity most effective for sedentary spp. (low juvenile & adult movement rates)
4. Spp. w/ long dispersal require large fraction of coastline in reserves

Botsford, Micheli, & Hastings. 2003. *Ecol. Appl*. 13(1) Suppl. S25-S31.

Scientific Consensus Statement on Marine Reserves & MPAs

- AAAS Annual Meeting, 17 Feb. 2001
  http://www.nceas.ucsb.edu/consensus/
- Lubchenco, et al. 2003. *Ecol.Appl*. 13(1) suppl. S3-S7.

Scientific Consensus Statement
Ecological effects w/in reserves

1. ↑s in abundance, diversity, productivity
   – long-lasting; often rapid
2. Due to: ↓mortality, ↓habitat destruction, indirect effects
3. ↓ P{extinction} for resident species
4. ↑ benefits w/ ↑ reserve area,
   – even small reserves have positive effect
5. Full benefits require full protection
   – Reserves better than MPAs

Scientific Consensus Statement
Ecological effects outside reserves

1. Spillover effects in adjacent areas:
   – ↑ size, abundance of harvested spp
2. Reserves replenish populations regionally
   – via larval transport

Scientific Consensus Statement
Ecological effects of reserve networks

1. Buffer environmental variability,
   – much greater protection than a single reserve
2. Effective networks:
   – span large geographic distances
   – include large area

   ("effective" = support long-term persistence)

Scientific Consensus Statement
Evidence for:

1. Reserves conserve both fisheries & biodiversity
2. Must include diverse marine habitats for (1)
3. Best method to protect resident spp
4. Require complementary mgmt tools
5. Require monitoring/evaluation (w/in & outside)
6. Provide benchmark to evaluate marine threats
7. Need reserve networks for long-term benefits
8. Immediate protection of marine reserves justified
   – central management tool

Conclusions

- Overharvest of marine fisheries
- Failure of fisheries management
  – Political reason: ratchet effect
  – Scientific reason: MSY vs. uncertainty
- Lower harvest = insurance
- Marine reserves
  – may prevent overharvest
  – can increase yield

Awareness Campaign

http://www.shiftingbaselines.org/

filmmaker Randy Olson
launched 24 Feb. 2003