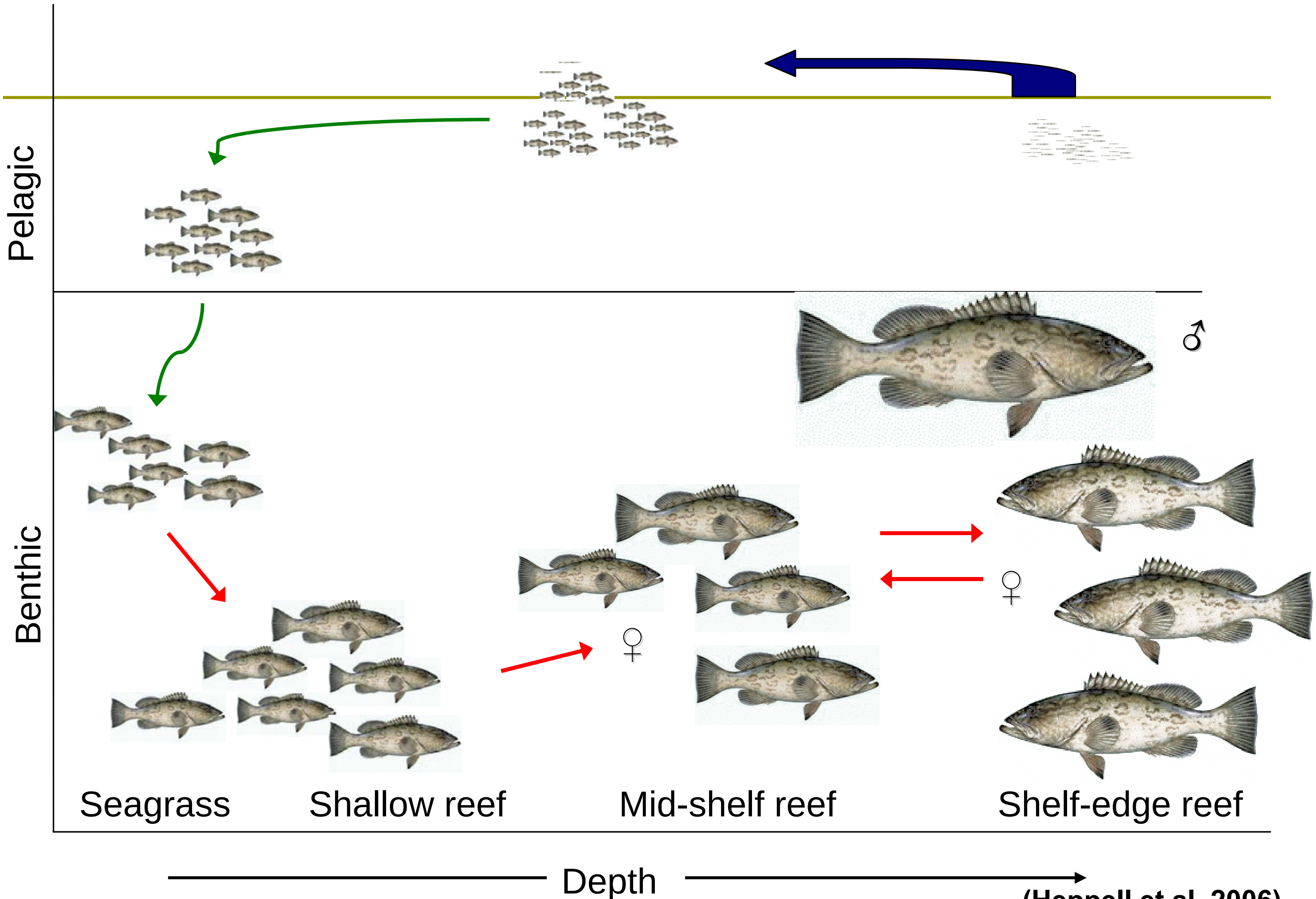
Review of effects from fishing mortality on protogynous species and implications for management

Sustainable Fisheries Div
SEFSC NMFS Miami Lab

General Life Cycle of Gag Grouper



(Heppell et al. 2006)

Sex transition …

Gag

- Sequential hermaphrodite protogynous (female → male)
- Sex transition
  - Exogenous clues: size related to group, behavioural …
  - Endogenous clues: absolute size, age, …
  - Combination
- Fishing effects
  - Sex ratio changes
  - Size-dependent fecundity females & males
  - Spawning aggregation size
  - Sperm limitation ?
  - Mating behavior and life history pattern ?

Research & Methods

- Observations
  - sex ratios,
  - fecundity output (fem)
  - mean size by sex
- Modeling
  - Huntsman & Shaaf 1994 (Grasby)
  - Armsworth 2001(coral trout Great Barrier Reef)
  - Alonzo & Mangel 2004 (California sheephead)
  - Heppell et al 2006 (gag Gulf of Mexico)

Huntsman & Shaaf

- Simulation model of Grasby (*E. cruentatus*)
  - Indicator: quantity of fertilized eggs from population (less influence by external factors, ie environment).

$$E' = Q * O$$

$$O = 1.2512 * SSB_{fZ} + 24.58$$

$$Q = \frac{SSBm_Z}{Fec_Z} \Big/ \frac{SSBm_M}{Fec_M}$$

Compensated and uncompensated protogyny

1. Uncompensated: F resulting changes of sex ratios did not trigger increase transition or early onset of maturation.
2. Compensated protogyny, fixed maturation: rate transition to male change as function of numbers in sex ratios (N fem:N mal).
3. Compensated protogyny, maturation varies: female maturation changed with increasing F
4. Compensated protogyny, fixed maturation: rate transition to male change as function of biomass of sex ratios (SSB fem:SSB mal).
5. Growth compensated protogyny, K varies: population growth rate increase with increasing F.

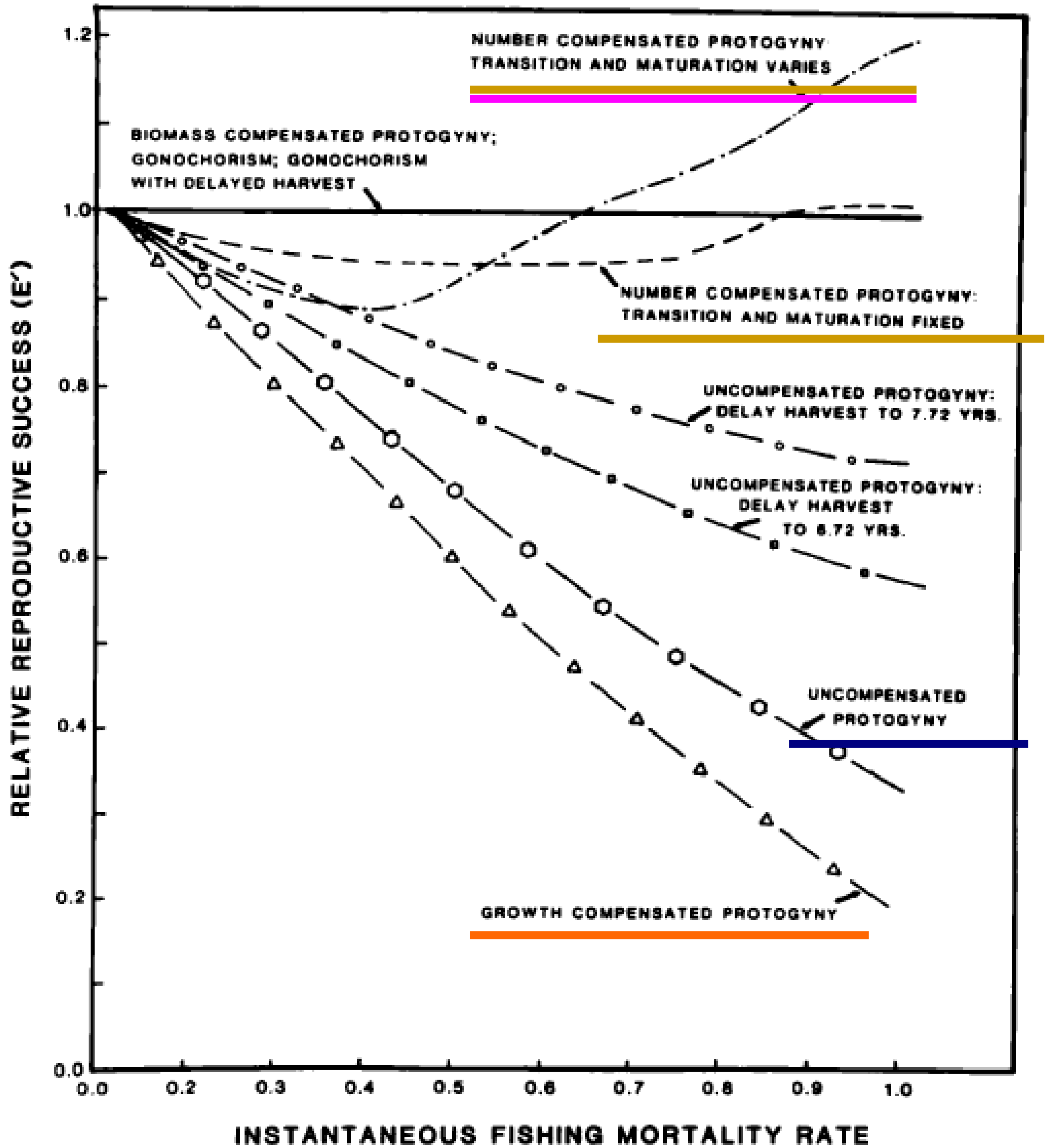


FIGURE 2.—Responses of the proxy for fertilized egg production to fishing in simulated gonochoristic and protogynous populations.

Conclusions Huntsman & Shaaf

a. Protogynous stocks may be far more vulnerable to F compared to gonochoristic stocks
b. Uncompensated protogyny: lose reproductive capacity as F increases
c. Compensation by numbers or biomass sex ratios reduces the impact of F on protogynous stocks.

Armsworth 2001

Simulations coral trout (*Plectropomus leopardus*)

Sexual transition control by

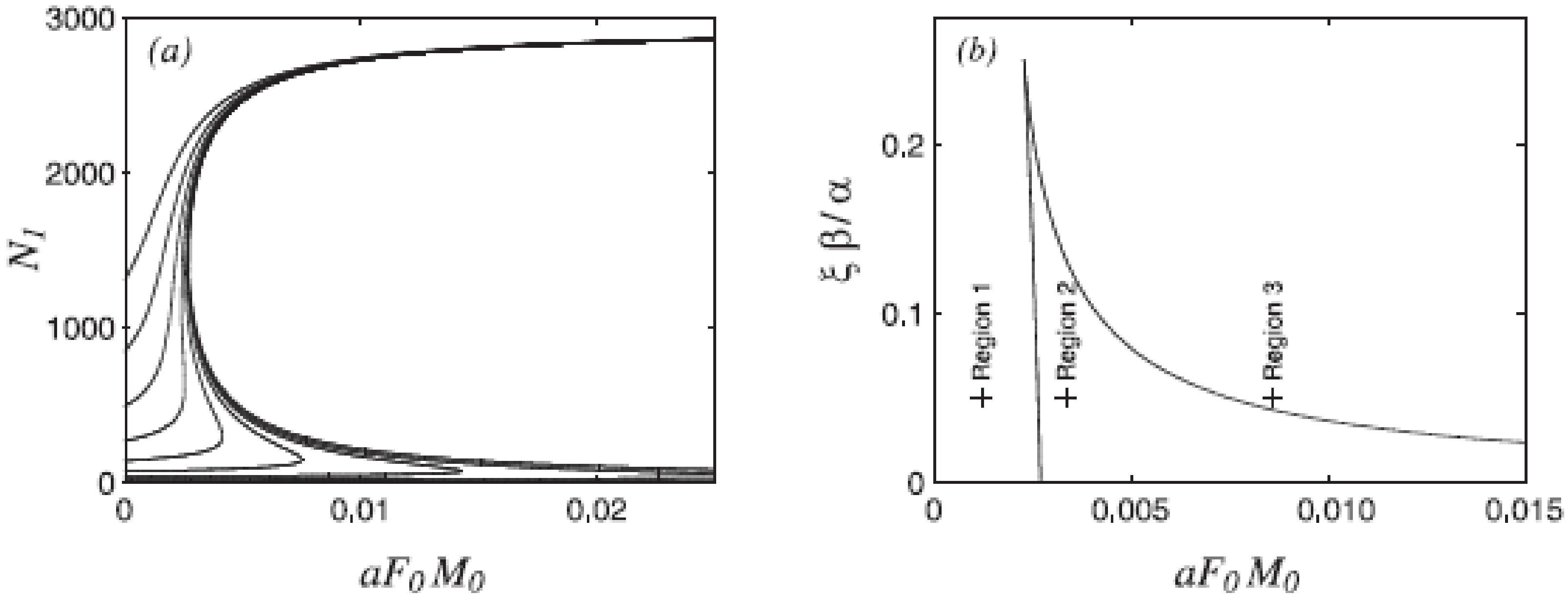
1. endogenous development schedule fixed, thus proportion of fem:mal @ age is constant
2. social factors, male transition a function of the mean age of the population.

Meta-populations with a pool dispersal of pelagic larvae

- Simulated a population with a partial open (larvae recruitment from outside, spawners can migrate.

… Armsworth 2001

Fig. 1. All figures were produced using the data given in Appendix A. (*a*) Cross-sections of the equilibrium surface plotted against aF_0M_0 for $\xi\beta/\alpha$ = [0, 0.0125, 0.025, 0.05, 0.1, 0.2, 0.4, 0.8, 1.6], given in increasing order of vertical intercept; (*b*) projection of the outlines of the cusp onto the (aF_0M_0, $\xi\beta/\alpha$) plane. The curves separate parameter space into three regions.



Alonzo & Mangel 2004

- Individual based simulation → Size distribution
- Individual/population → Fecundity
- Population → sex ratio, fertilization rate, pop size (F)
- One or several mating sites with a common Larval pool
- California sheephead (*Semicossyphus pulcher*)

… Alonzo & Mangel 2004

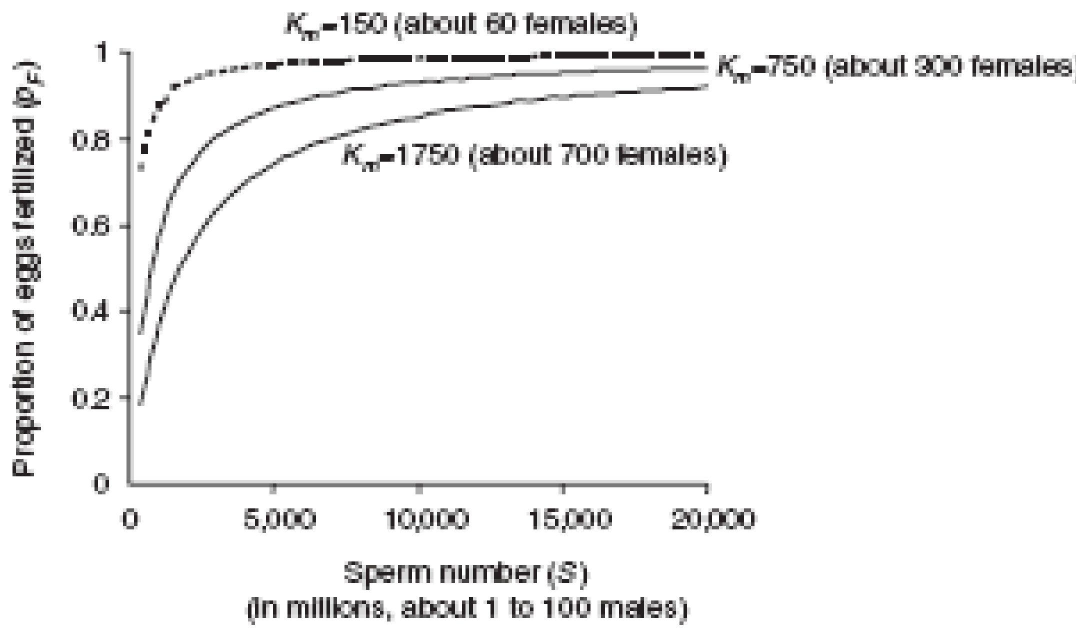


Figure 2

Fertilization rate as a function of the number of eggs and sperm per mating site. The saturation parameter $K_m = \kappa E + \chi$ is taken from Equation 9.

… Alonzo & Mangel 2004

- Measures of SSB per recruit
  - Egg production SSB fem
  - Sperm production SSB mal

$$p_F = \frac{S}{1 + (\kappa E + \chi)S}$$

- Effects of Marine reserves (% population protected)
- Fixed sex-transition pattern

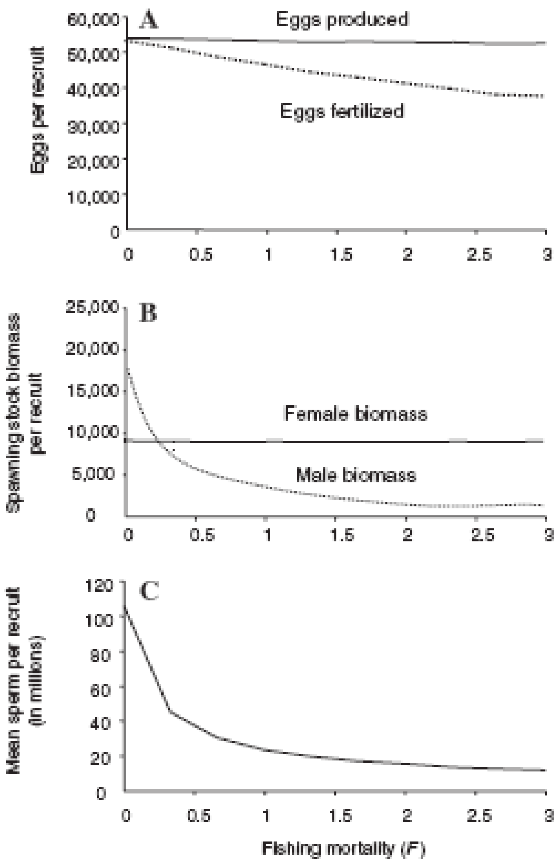


Figure 3

Spawning-per-recruit measures. Results are presented for the sex-changing stock with one mating site when $L_f = L_c$ and r=1. Means across 20 simulations are given. For details see the general text.

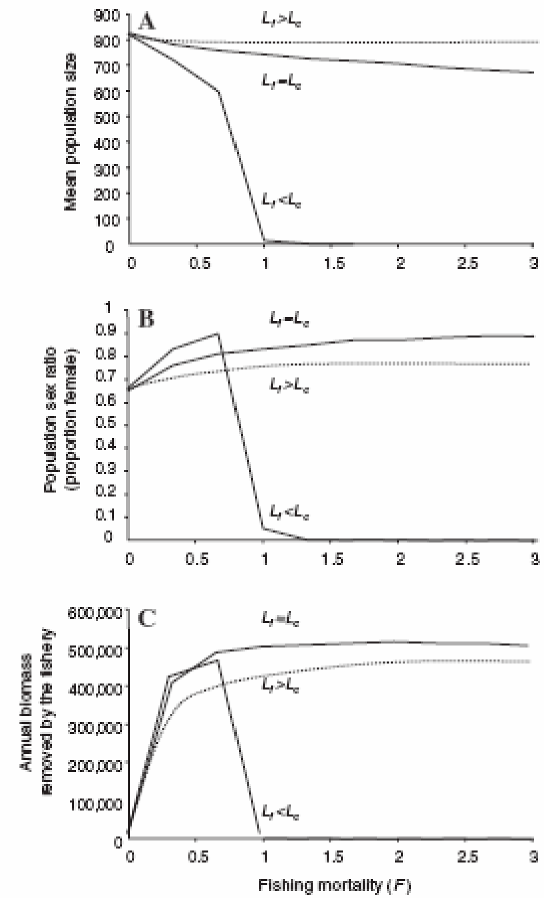
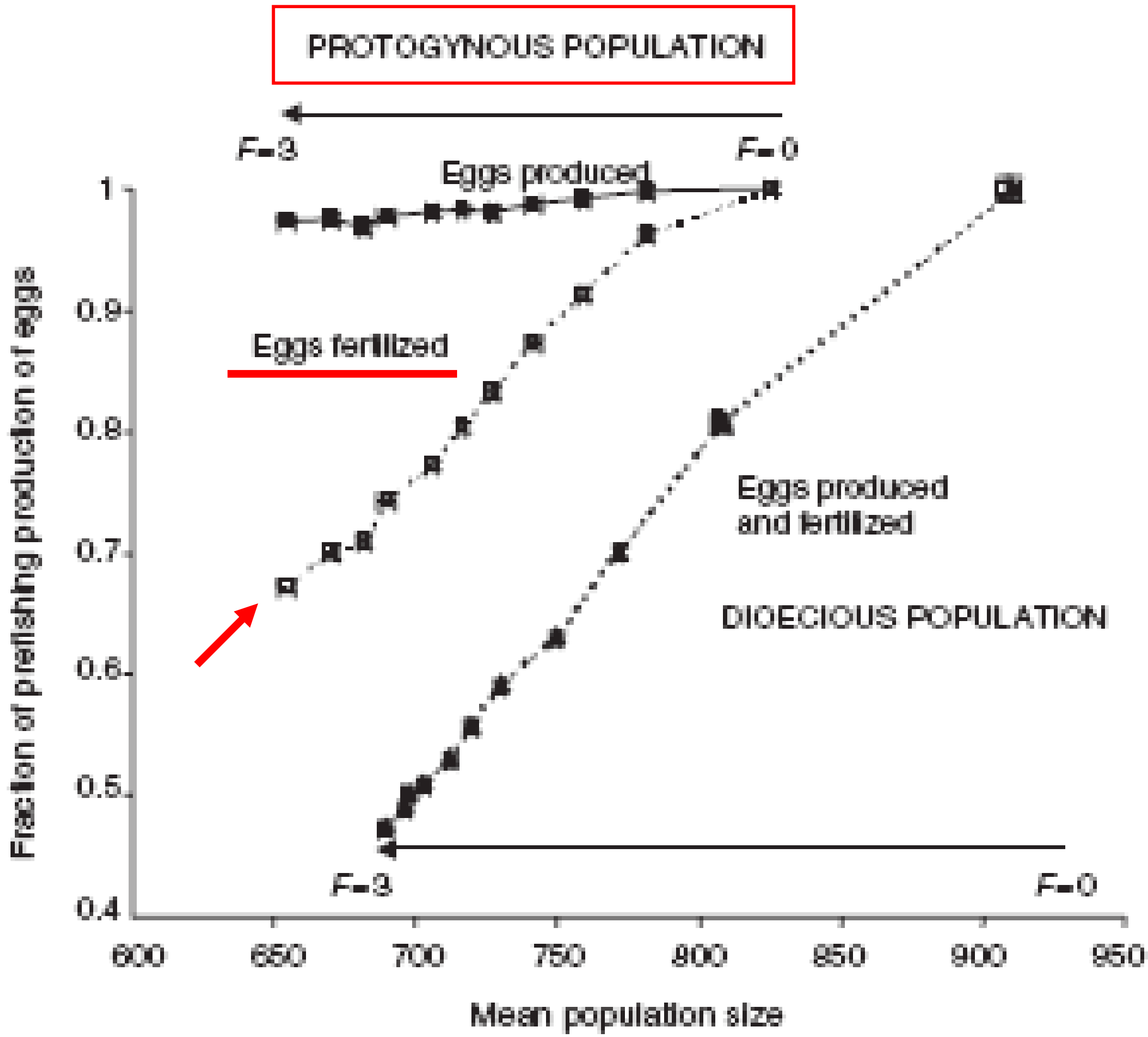


Figure 4

The effect of size-selective fishing on stock dynamics. We present results for the sex-changing stock with one mating site when r=1. Means across 20 simulations are given. For details see the general text.



PROTOGYNOUS POPULATION
F=3
F=0
Eggs produced
Eggs fertilized
Eggs produced and fertilized
DIOECIOUS POPULATION
F=3
F=0
Fraction of prefishing production of eggs
1
0.9
0.8
0.7
0.6
0.5
0.4
600
650
700
750
800
850
900
950
Mean population size

Conclusions Alonzo & Mangel

a. Protogynous stock with fixed sex transition pattern will respond differently that an equivalent dioecious stock to F.
b. Response modulated by mating system, reproductive behavior, pop dynamics.
c. Protogynous stocks more sensitive to mating aggregation size and sperm limitation.
d. Traditional spawning per recruit measures are especially problematic for sex-changing spp
   - Total SSBmal ~ SSBfem depends largely on sperm/egg fertilization ratio and sperm size production.
e. Marine reserves ? Dependent on mating systems, etc. + effort redistribution and dynamics of stock.

Heppell et al 2006

- Simulations on Gag GOM (using 2001 SA results)
- Migration of females to spawning sites, residence of males in spawning sites (Koening & Coleman) → dynamic segregation/aggregation of mature stock in time-space.
- Model: pop dynamics gag ...
  - Fertilization success declines with the proportion of males in population (asymptotic)

Fertilization rate

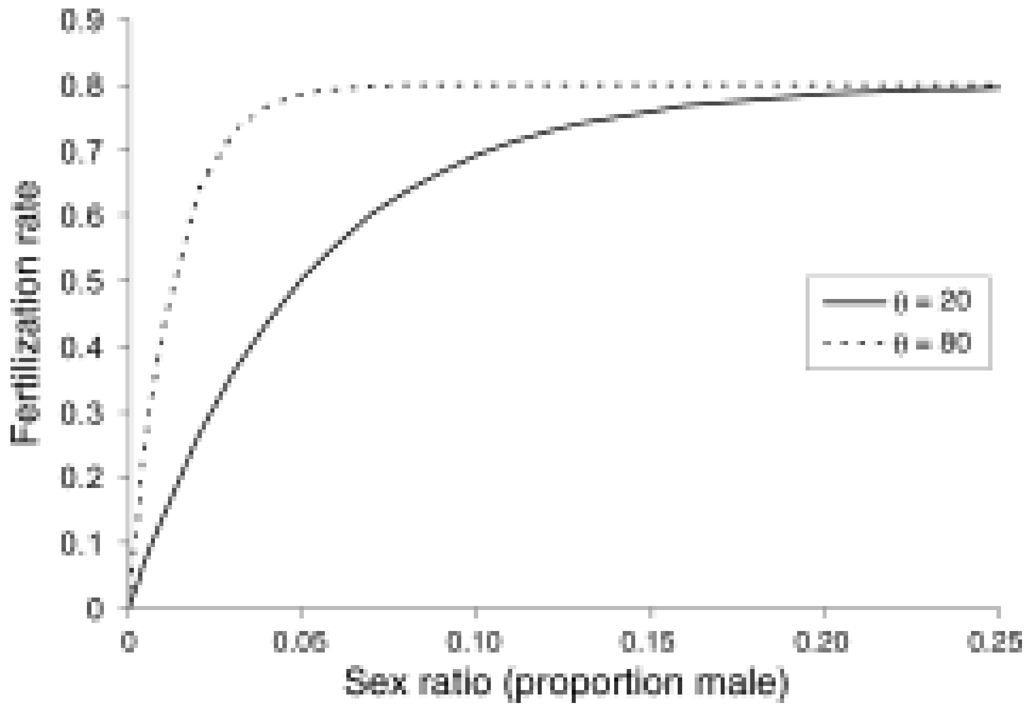
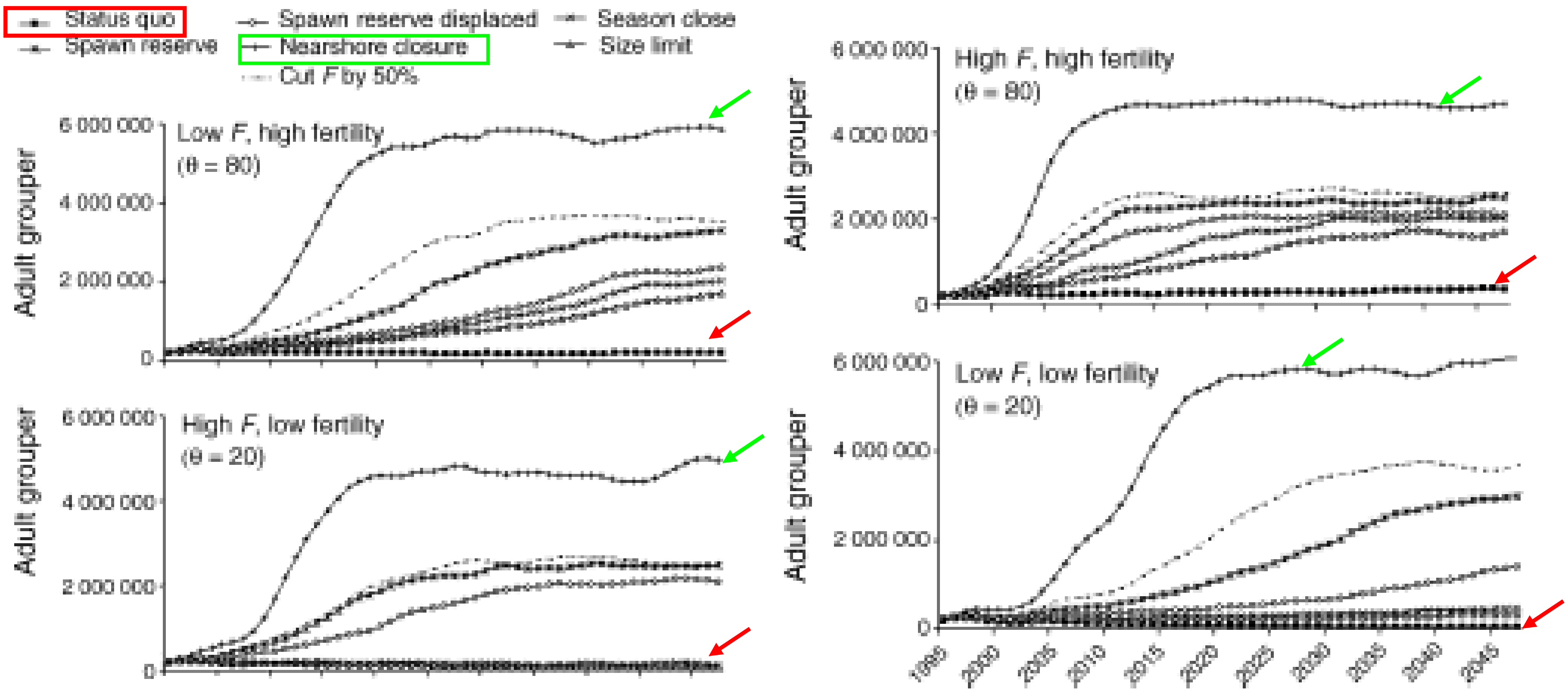


Fig. 3. Model relationship between fertilization rate and sex ratio (proportion of males), based on two different levels of fertility function, θ (Eq. 8).

Management scenarios

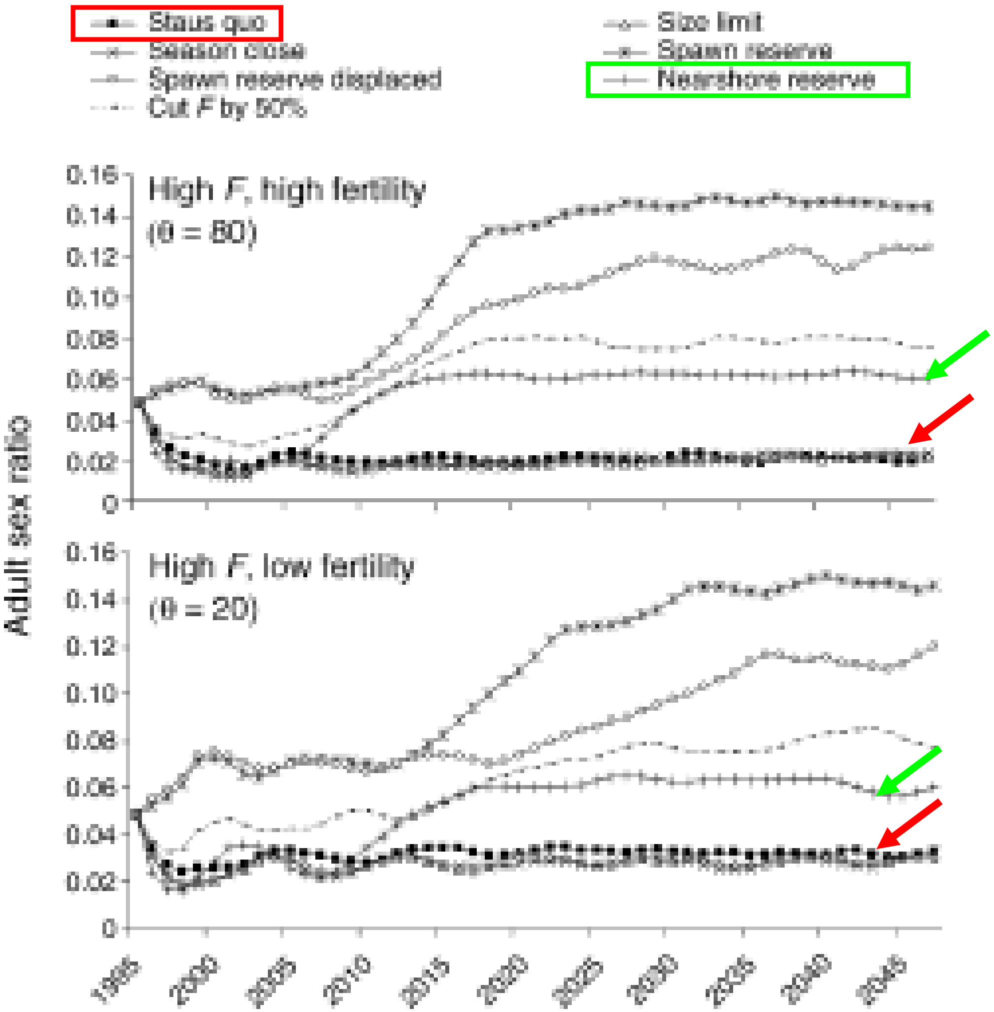
Management options

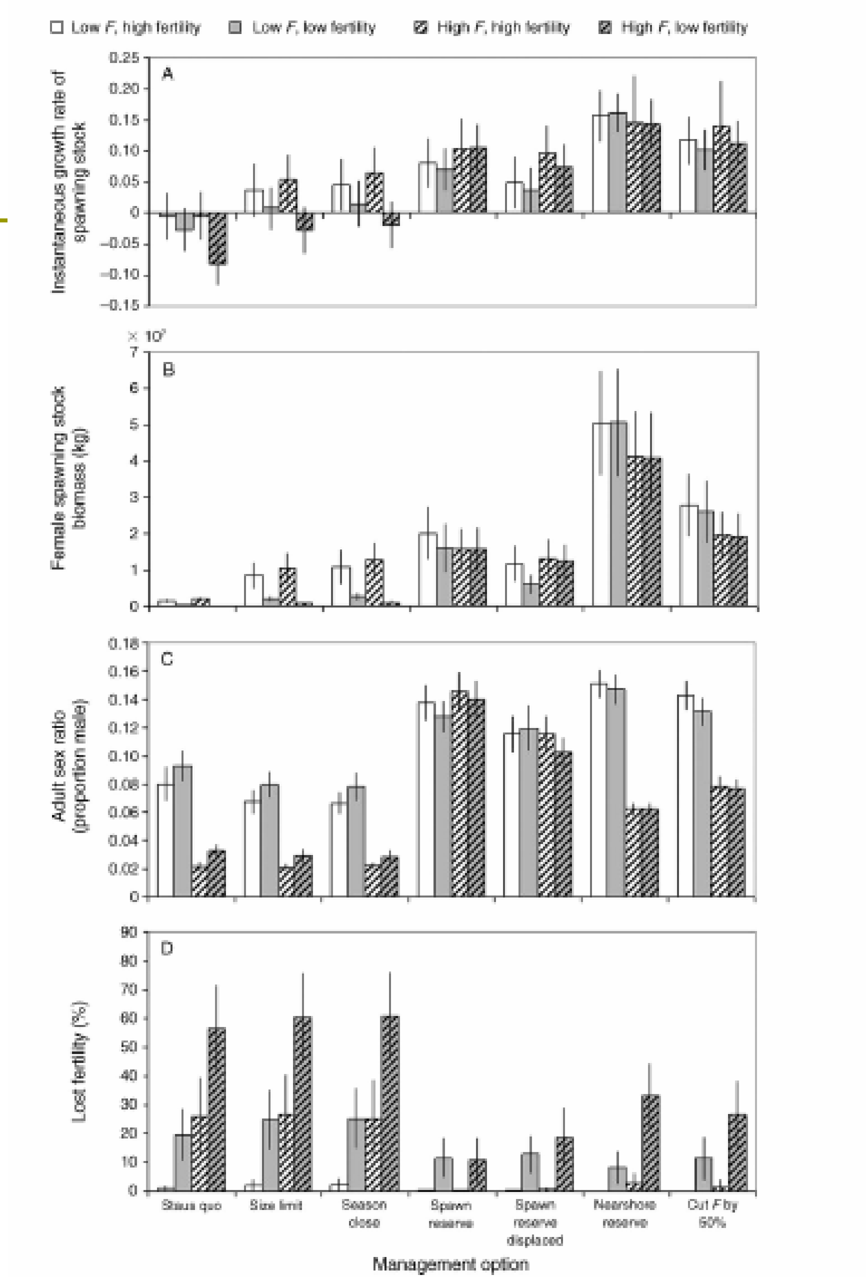
1. Status quo F level 2001 SA
2. Increase min-size: reduce F age1 and immature
3. Size limit + spawning season closures (Jan-Mar): zero F for 1st quarter
4. Size limit + spawning closure (zero F for males, zero F 1st quarter females)
5. Spawning closure + redistribution of effort outside ....
6. Near-shore closure (zero F immature and females)
7. 50% reduction on F.



Projections of spawning stock size (mature) for 2 levels of F, and 2 levels of fertility rates. From Heppell et al 2006 Fig 4.

Projections of adult sex ratio (proportion male). From Heppell et al 2006 Fig 5.





Low F, high fertility
Low F, low fertility
High F, high fertility
High F, low fertility
A
Instantaneous growth rate of spawning stock
B
× 10⁷
Female spawning stock biomass (kg)
C
Adult sex ratio (proportion male)
D
Lost fertility (%)
Staus quo
Size limit
Season close
Spawn reserve
Spawn reserve displaced
Nearshore reserve
Cut F by 50%
Management option