Issues in assessment modeling for protogynous fishes

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Typical age-structured assessment model

- Catch-at-age time series
- Selectivity curve
- Recruitment to fishery age (or ogive)
- Maturation ogive
- Fertility-weight relationship
- Spawner-recruit curve
- Constant natural mortality
- Constant catchability
- Closed population

Characteristics of sex-changers that mess this up

- Catch-at-age time series
- Selectivity curve

- Varies by sex, because males are older AND often have different behaviors/habitats/ desireability

Characteristics of sex-changers that mess this up

- Age at recruitment to fishery (or ogive)
- Maturation ogive
- Fertility-weight relationship

- Recruitment to fishery likely to be 100% for youngest males
- Need separate ogive for transition to male probability-at-age
- Strong sex ratio skew likely limits fertility

Characteristics of sex-changers that mess this up

- Spawner-recruit curve
- Constant natural mortality
- Constant catchability
- Closed population

- S/R may be dependent on relative abundance of males and females
- Natural mortality and catchability estimates needed for both sexes due to differences in habitat and behavior
- Females transition to males, "disappearing" from the female stock biomass but not dying

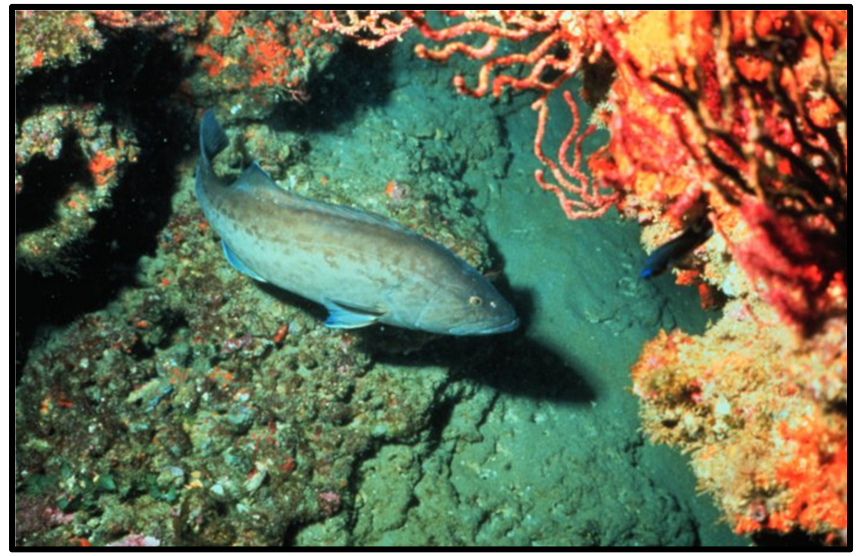
Typical data-poor assessment model based on catch history

- Catch time series
- Basic life history
  - Natural mortality
  - Age at maturity
- Ratio of current biomass to pre-fished biomass
- Aggregation behavior
- Need for sex-specific catch (possible but not always available)

Gag Grouper Model

Heppell, Heppell, Coleman and Koenig, *Ecological Applications*

- Effects of harvest on hermaphrodites
- Compare the relative impacts of protected areas that are sex-specific and time/location specific
- Compare benefits of protected areas with reductions in fishing pressure
- Non-spatially explicit



Two models

- Model I = low fishing mortality rates
  - F_{female}= 0.4, F_{male}= 0.15
- Model II = high fishing mortality rates
  - F_{female}= 0.6, F_{male}= 0.6

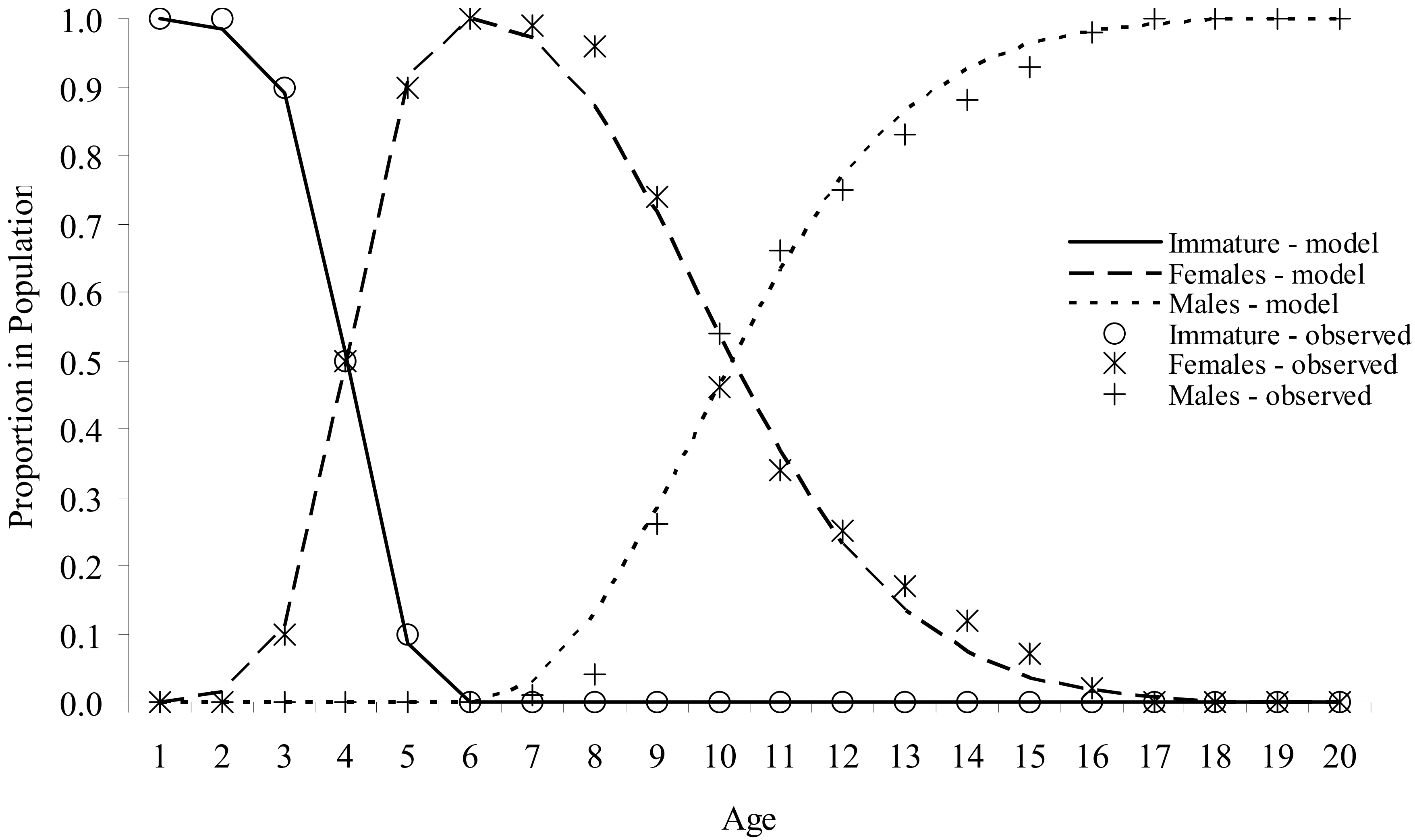
$$Z = F(spawn) + F(feed) + M$$

0.25 → F(spawn); 0.75 → F(feed)

Example: spawning reserve

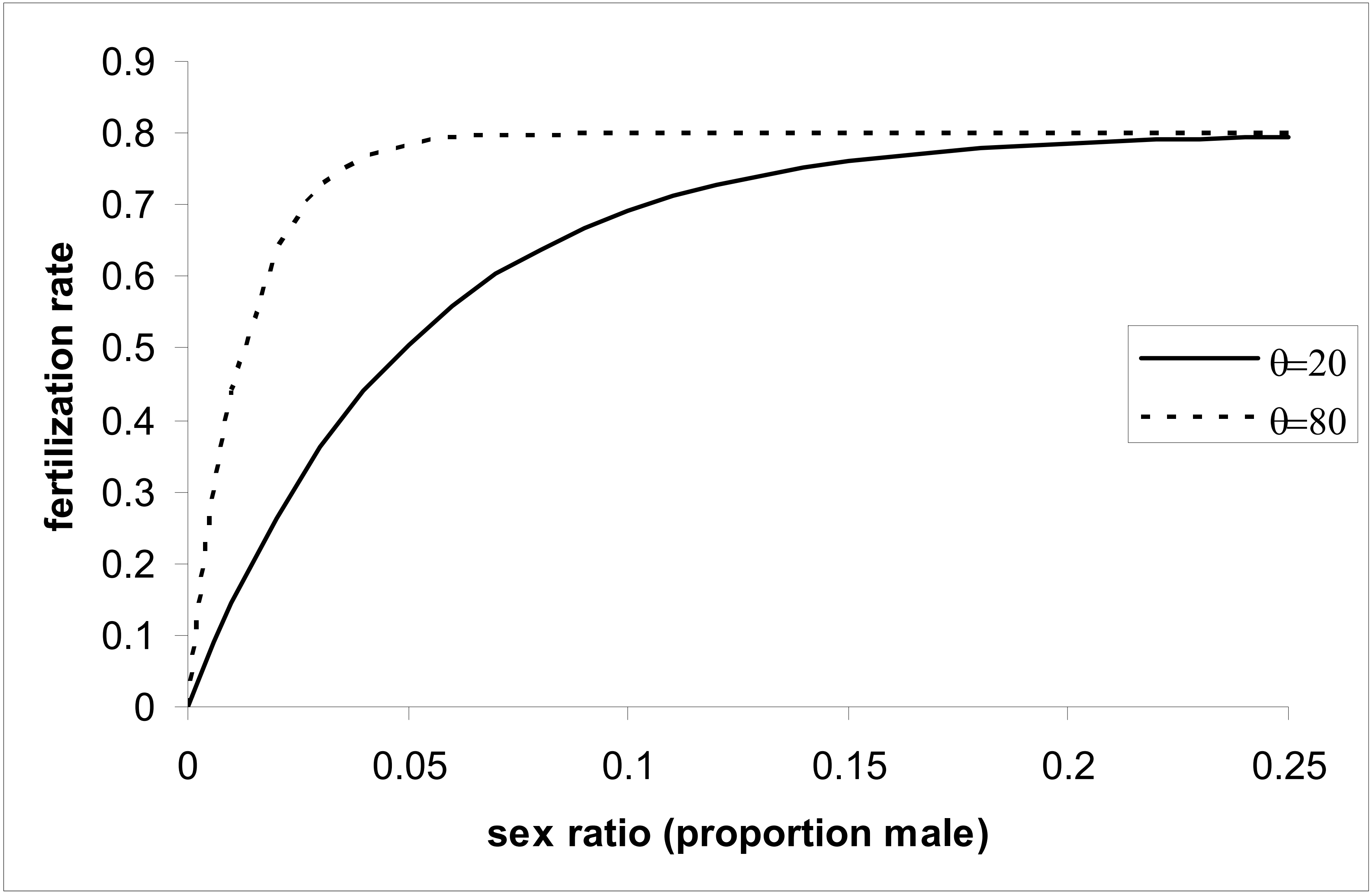
$$Z = F(spawn)*0 + F(feed) + M = F(0.75) + M$$

Transition probabilities for each age class = equations fit to observational data, assuming constant recruitment

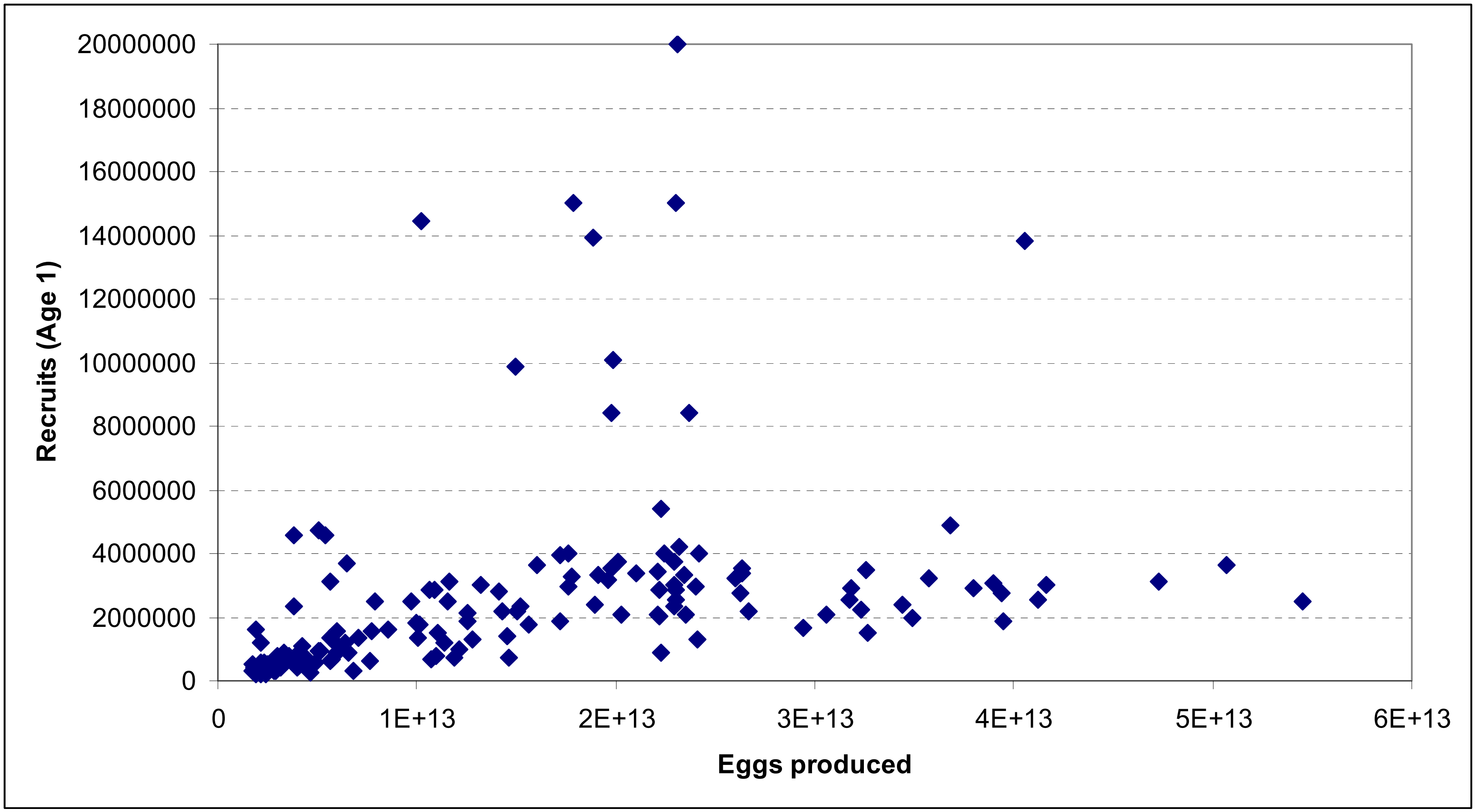


Observed = McGovern et al. 1998

Fertility as a function of sex ratio



Stochastic recruitment – hockey-stick function with log-normal random multiplier on egg survival (mean = 1, stdev = 0.3) and occasional "good" years (5-fold increase in egg survival, frequency = 0.15).



Management Scenarios

A: Status quo – 1996 fishing mortality rates

B: Increase size limit to 24 inches (=age 2-3)

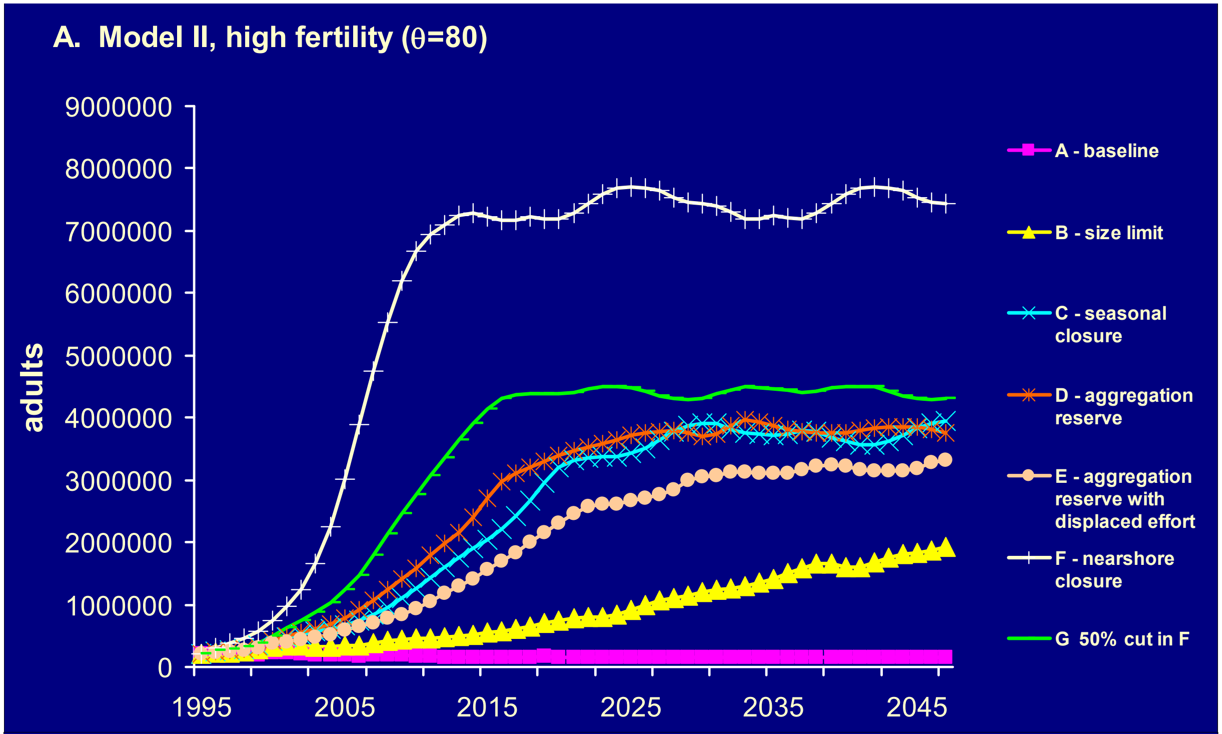
C: Seasonal closure for all size classes January-March (spawning season)

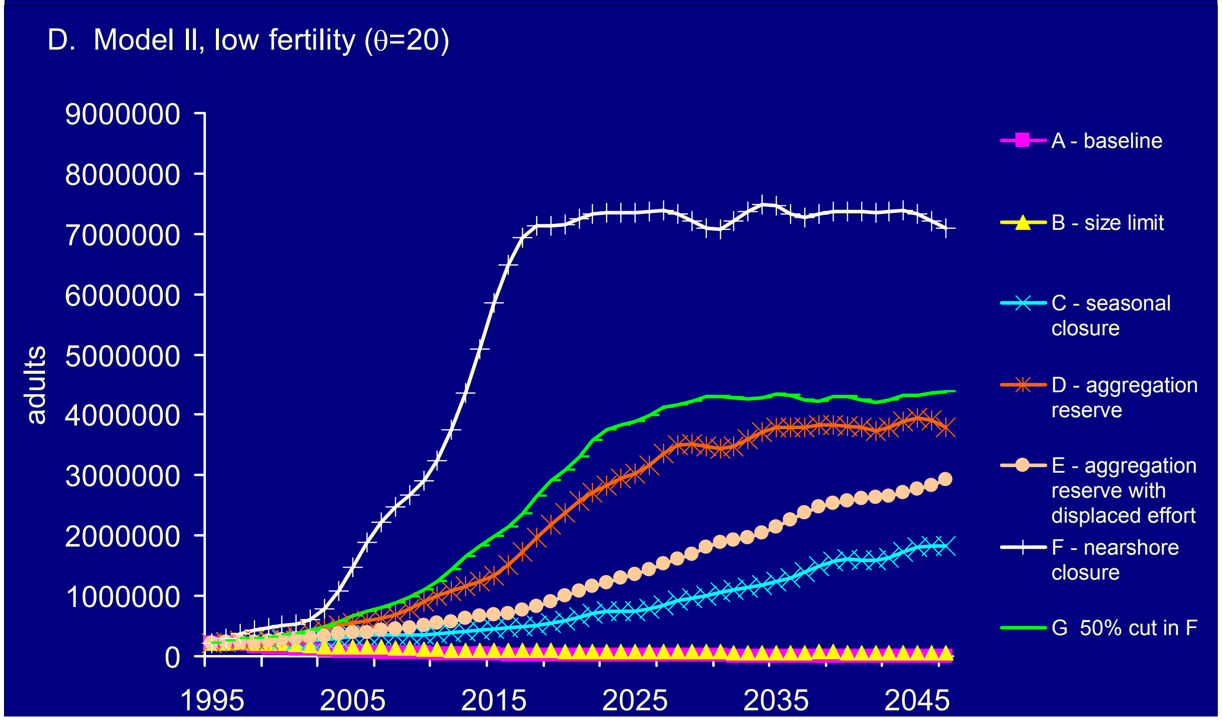
D: Aggregation reserve (protects spawners and males)

E: Aggregation reserve with displaced effort on females

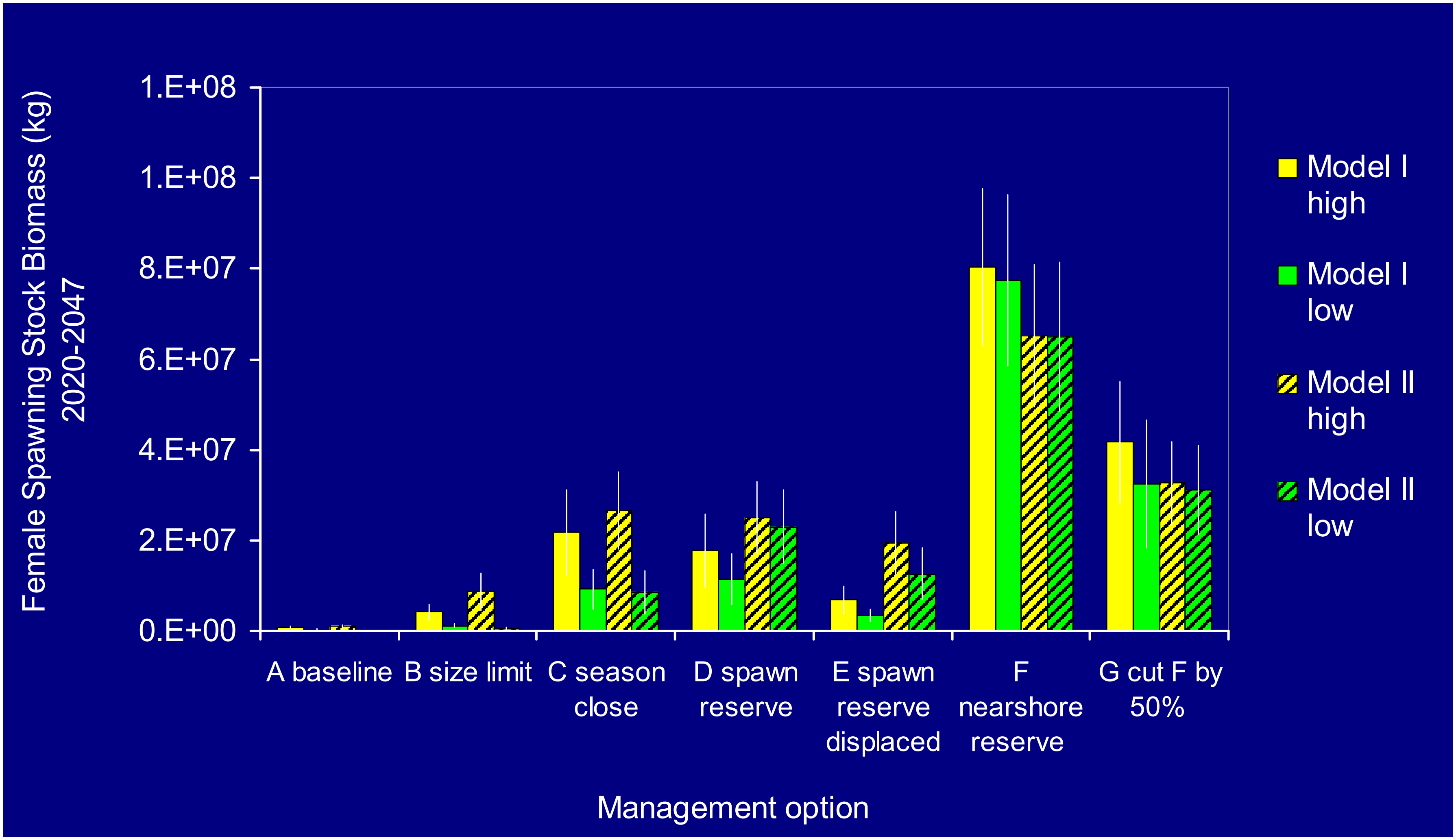
F: Shallow water reserves (protect females May-January)

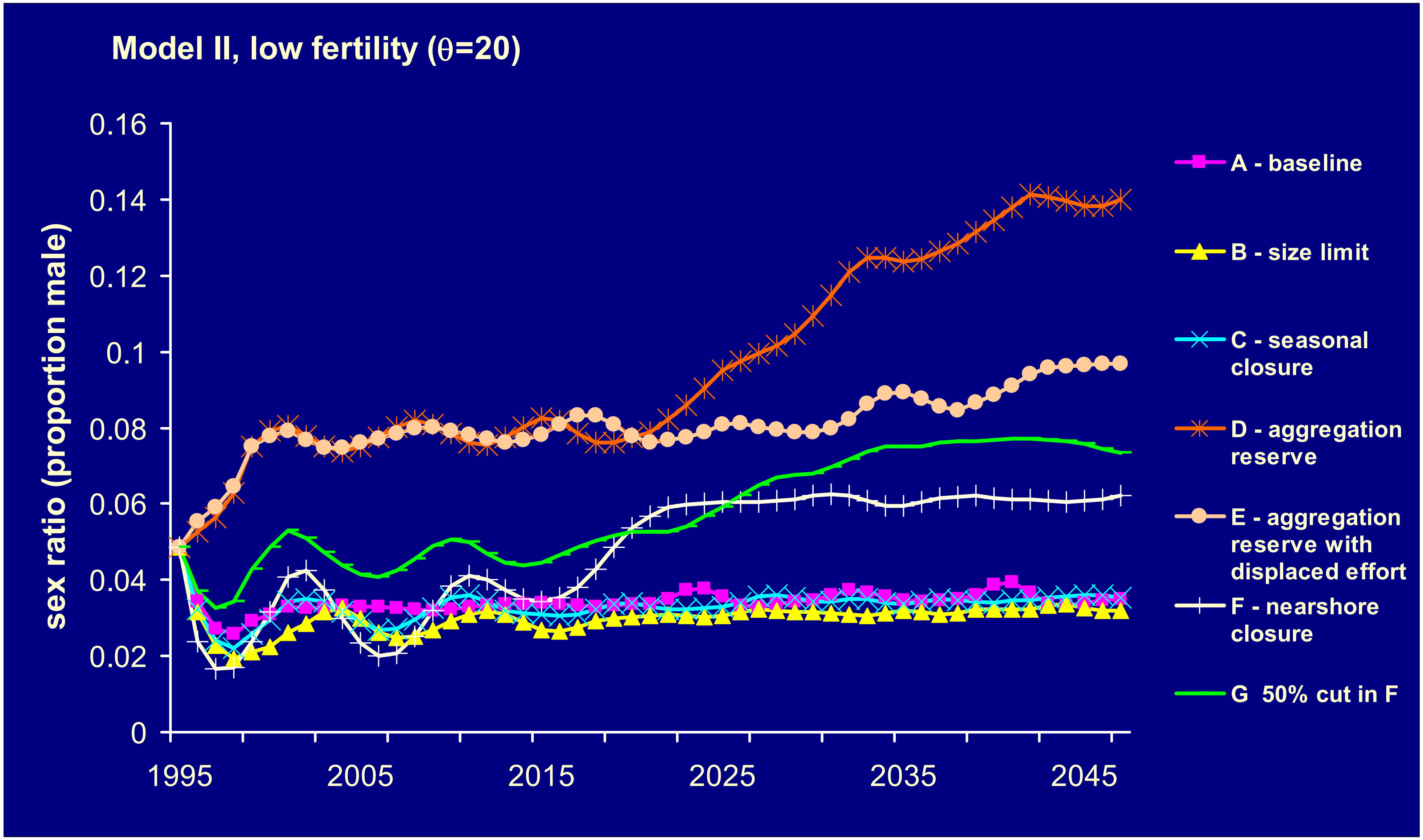
G: Cut fishing mortality by 50% for all


A. Model II, high fertility (θ=80)
adults
9000000
8000000
7000000
6000000
5000000
4000000
3000000
2000000
1000000
0
1995
2005
2015
2025
2035
2045
A - baseline
B - size limit
C - seasonal closure
D - aggregation reserve
E - aggregation reserve with displaced effort
F - nearshore closure
G 50% cut in F


D. Model II, low fertility (θ=20)
adults
9000000
8000000
7000000
6000000
5000000
4000000
3000000
2000000
1000000
0
1995
2005
2015
2025
2035
2045
A - baseline
B - size limit
C - seasonal closure
D - aggregation reserve
E - aggregation reserve with displaced effort
F - nearshore closure
G 50% cut in F

Model I = low fishing mortality rates   Model II = high fishing mortality rates
High = high fertilization with few males   Low = low fertilization with few males



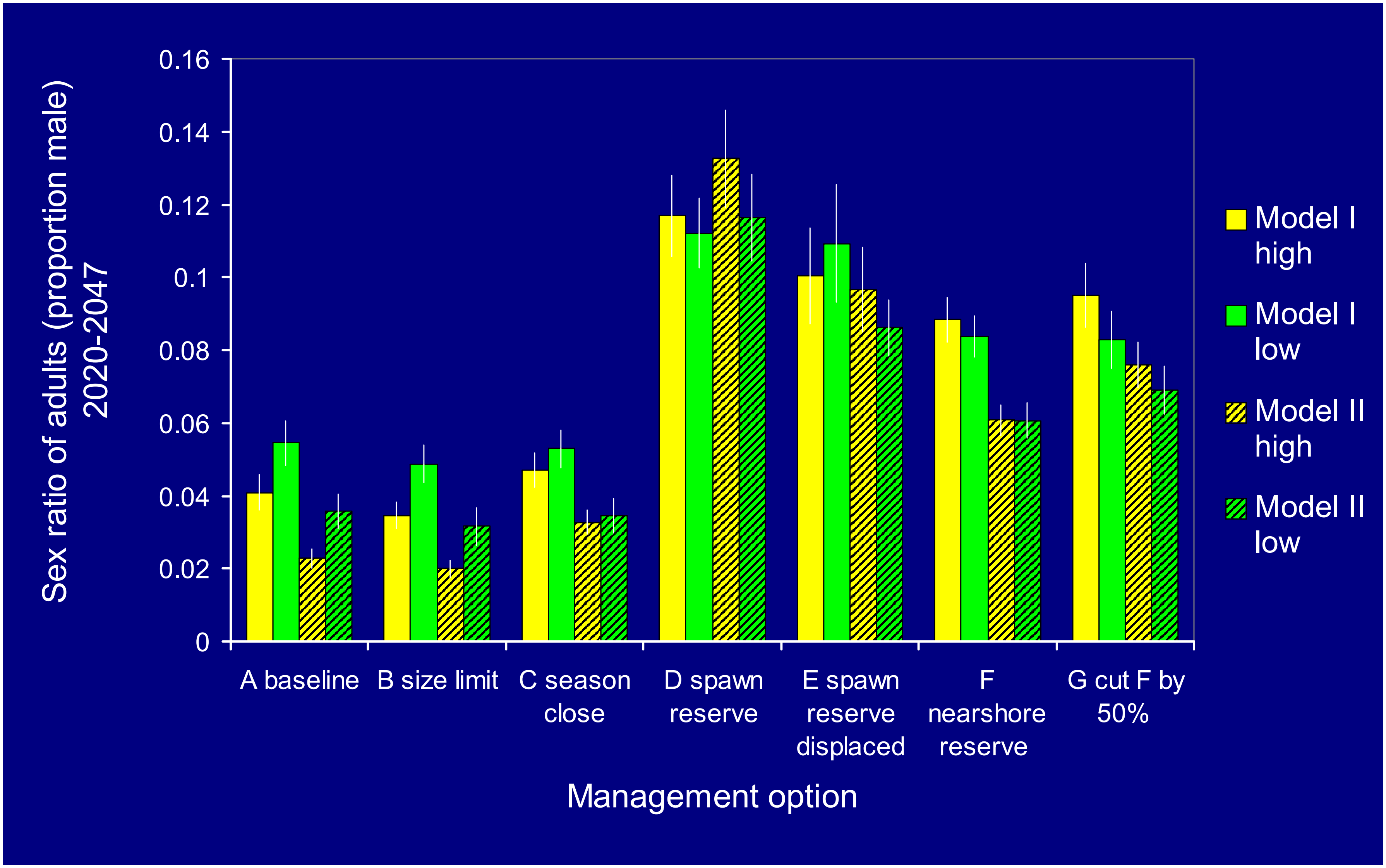

Model II, low fertility (θ=20)
sex ratio (proportion male)
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
1995
2005
2015
2025
2035
2045
A - baseline
B - size limit
C - seasonal closure
D - aggregation reserve
E - aggregation reserve with displaced effort
F - nearshore closure
G 50% cut in F

Model I = low fishing mortality rates

Model II = high fishing mortality rates

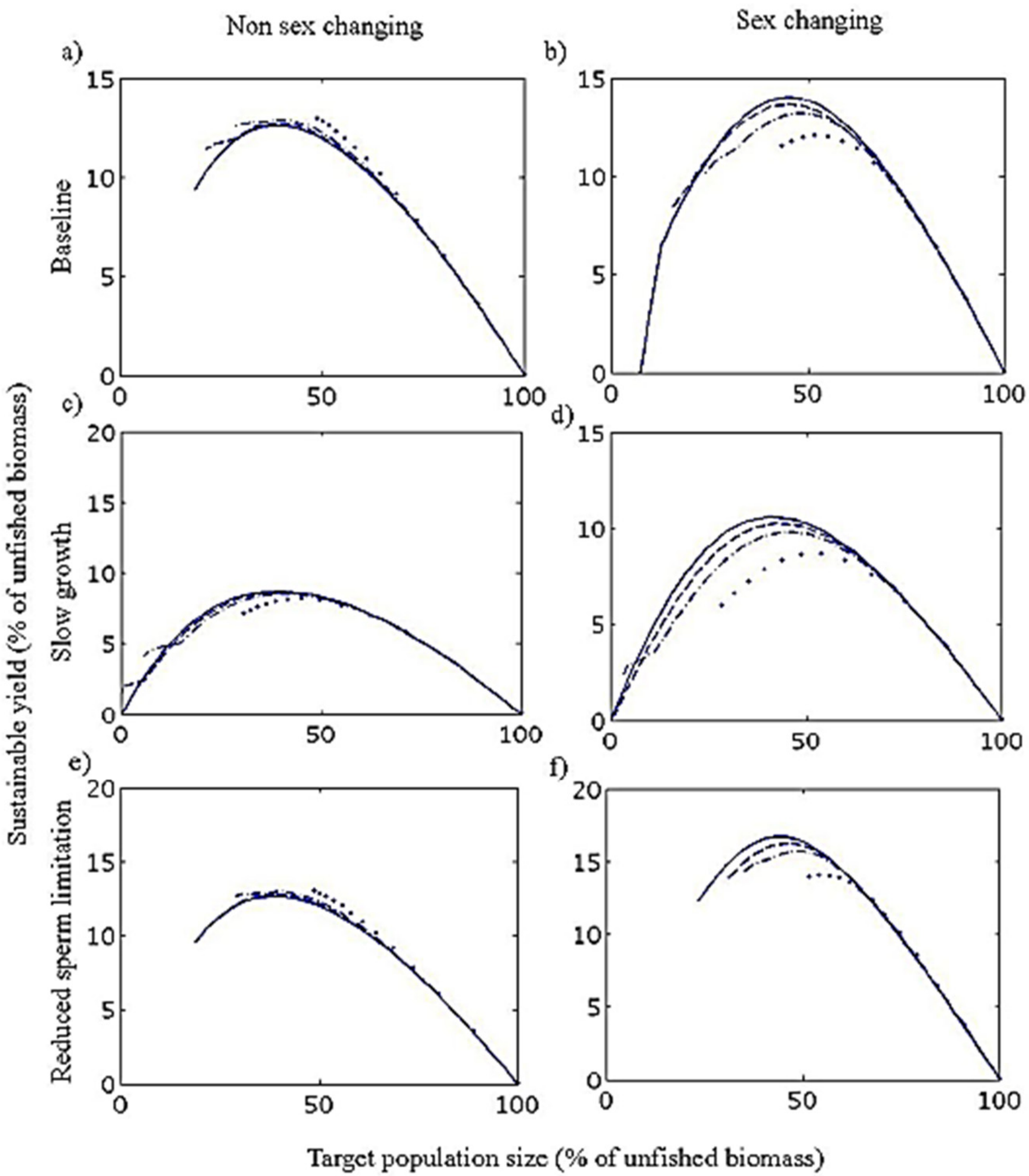
High = high fertilization with few males

Low = low fertilization with few males



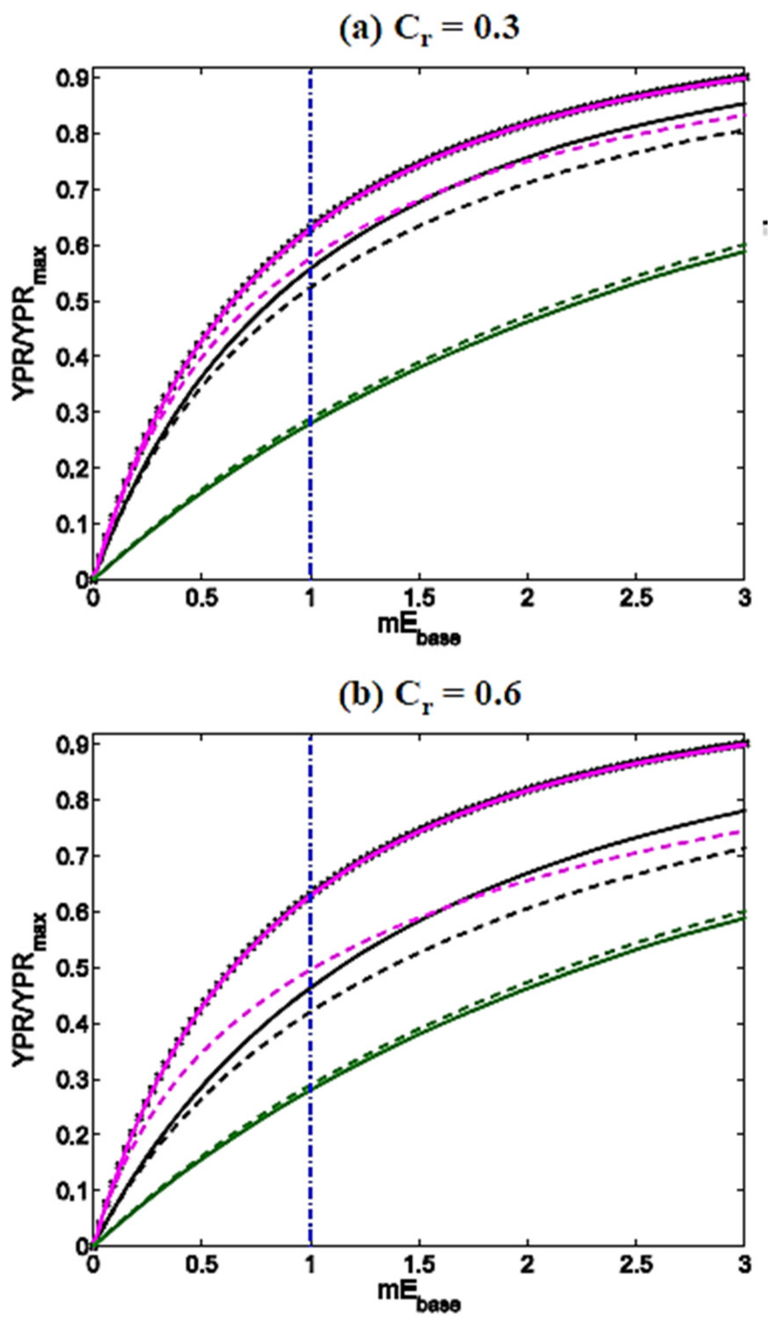
Comparing effectiveness

- Population recovery
  - Nearshore reserve > 50% cut in F > spawning reserve >= seasonal closure > size limit
- Biomass
  - Nearshore reserve >> 50% cut in F > spawning reserve = nearshore closure = seasonal closure > size limit
- Sex ratio (effective population size)
  - Spawning reserve > nearshore reserve = 50% cut in F > seasonal closure = size limit
- YPR? Harvestable biomass? Not compared. But undoubtedly lowest for Nearshore reserve closure, because it has the largest impact on Z (total mortality)



Chan, NCS, et al. (*in press, Ecological Applications*)
Effects of sex change on the implications of marine reserves for fisheries.

Dashed lines = increasing proportion of fishable area in reserves



Grüss A, Kaplan DM, Robinson J (*in final revision*) Evaluation of the effectiveness of marine protected areas protecting tansient spawning aggregations in data-limited situations. Marine Ecology Progress Series

C_r is the fraction of spawning aggregation sites in reserves

mE_{base} is the exploitation rate relative to the baseline (fished, no MPA) scenario.

Each line is a different management or fish behavior scenario, with combinations of redistribution of fishing effort and fish spawning site fidelity (dashed lines).

Initial model parameters

- Reproductive strategy
  - Gonochoristic (base model)
  - Protogynous (fixed transition)
  - Protogynous (plastic transition – sex ratio dependent)
- Sperm limitation (depensation caused by skewed sex ratio)
  - Weak or strong
- Fishery
  - Aggregation only
  - Aggregation >> non-aggregation
  - Non-aggregation
  - Both (switching?)

Initial model parameters

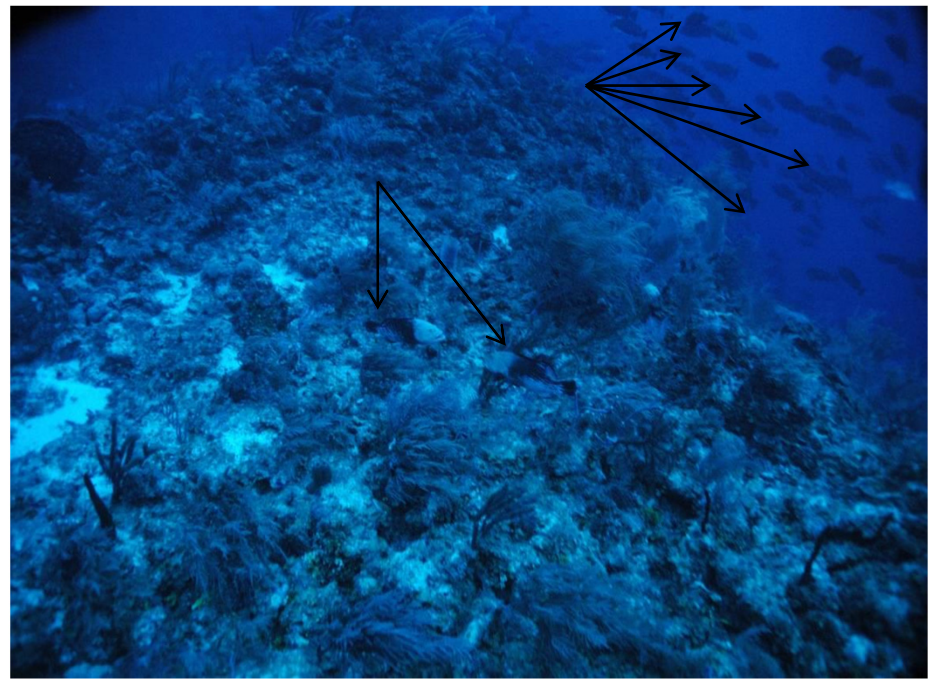
- Productivity
  - Female age/weight and fecundity
  - Juvenile survival
    - Density dependence strong/weak
  - Size-specific reproductive success
  - Maternal effects
  - Sperm limitation

Behavioral considerations

- Movement
  - Territorial/Roving
  - Spawning site fidelity
  - Corridors
  - Gender differences
- Reproductive interactions
  - Lek-like behaviors
  - Competitive interactions
- Behavioral learning
  - Juvenile to adult transition
    - Strong vs weak

Competitive interactions

- Mate competition vs. Sperm competition
- Aggregation vs. Pair/haremic spawning
- Male-male antagonistic feedback



Reference points?

- MSY
  - Tricky biology and behavior
  - Variable S/R curves – what should be on the x-axis?
  - Sex-specific?
- YPR and EPR
  - Deterministic, may not capture non-linearities like effects of sex ratio
- Female or male SSB/SSB_0
  - Same problem, plus issues with sex change plasticity
- Sex ratio (actual or operational)
  - Problematic for species with episodic recruitment
- Age distribution
- Observed productivity/recruitment

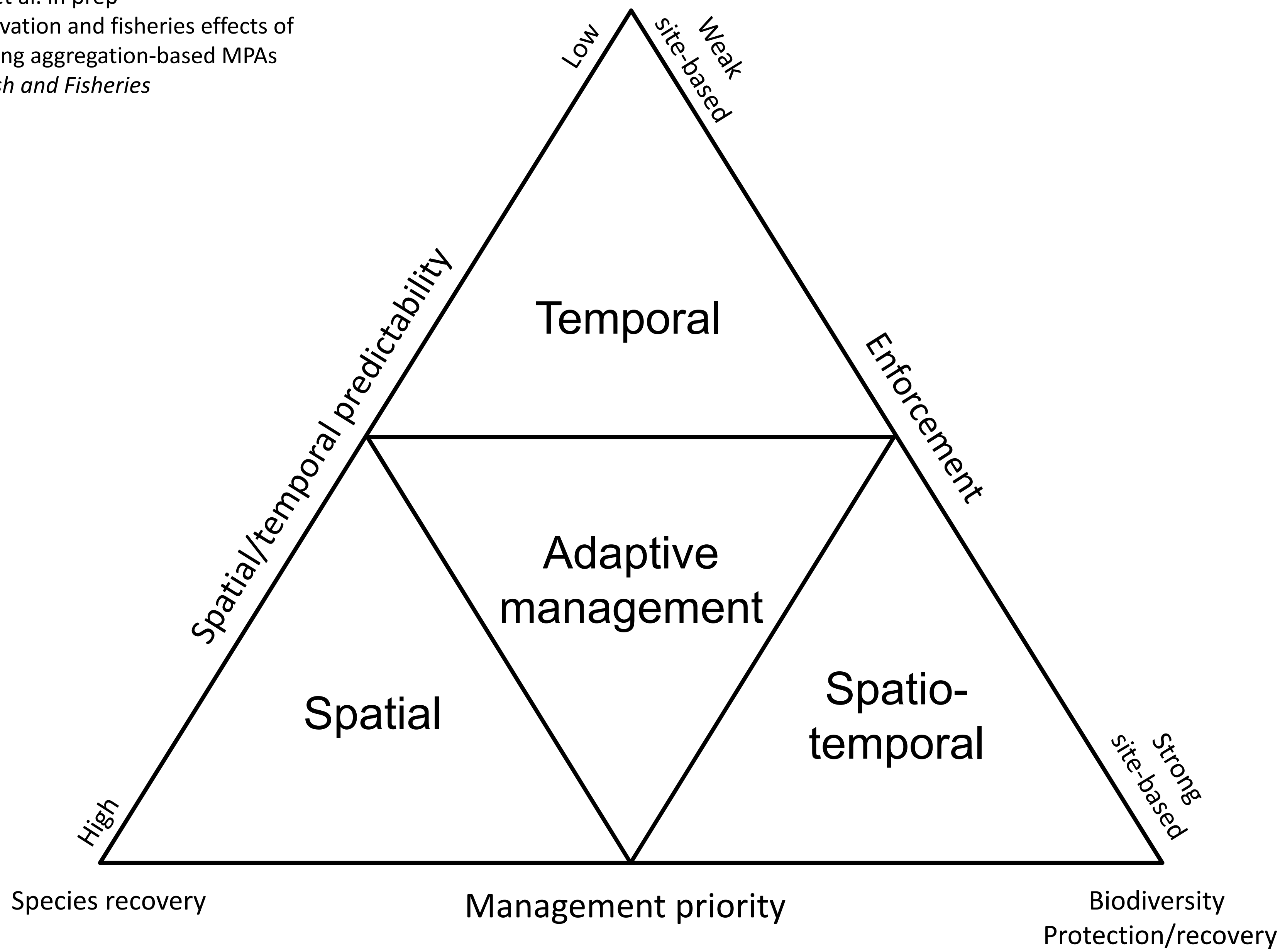
S/R curves – options?

Management considerations

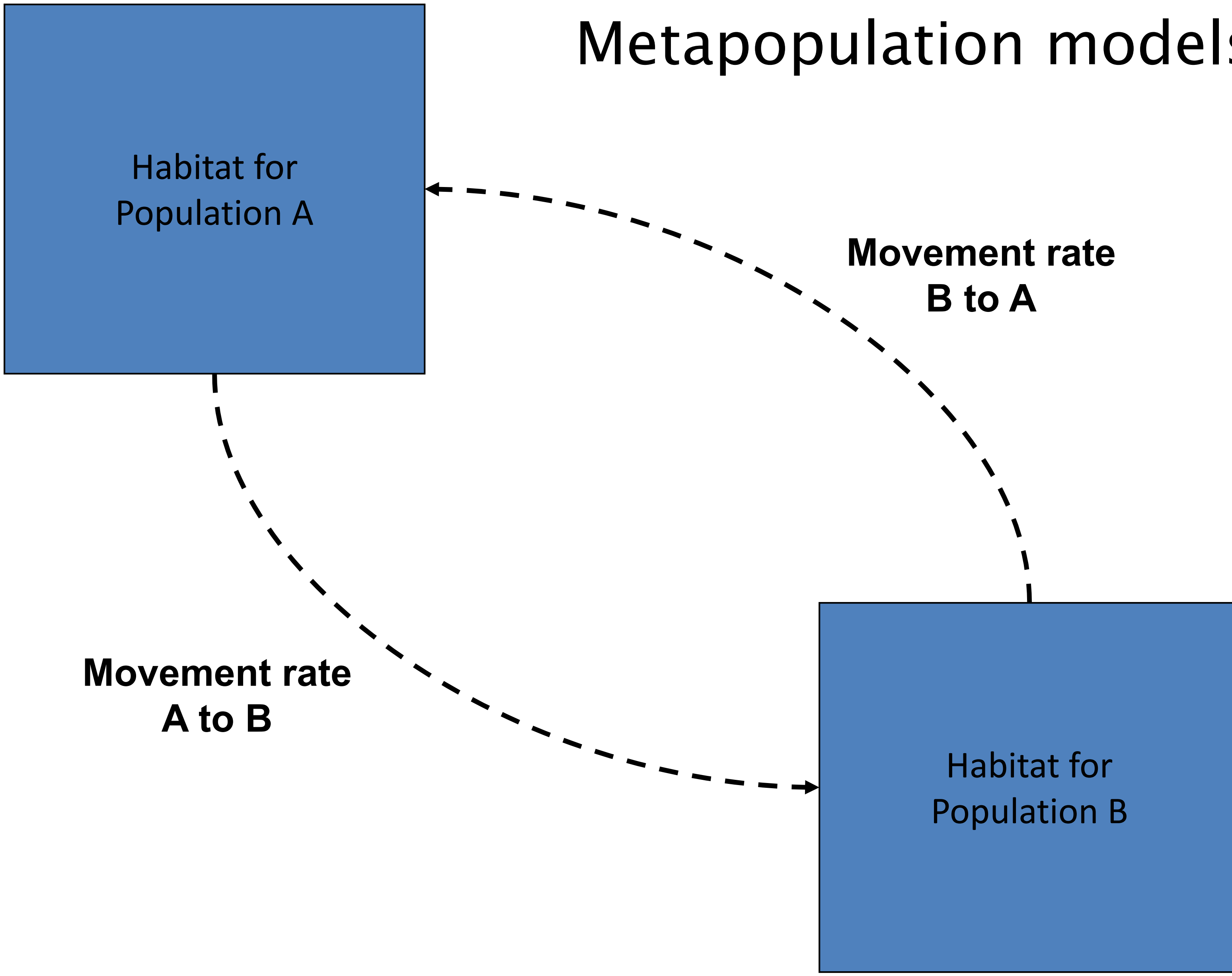
- Size limits
  - Discard mortality
- Bag limits
  - Likely to result in differential fishing mortality by age and sex
- Area closures
  - Enforcement
  - Efficacy when fishing effort is redistributed
  - Identification of "correct" areas, e.g., spawning sites
- Temporal closures
  - Enforcement
  - Efficacy when fishing effort is redistributed
  - Identification of spawn timing

	Aggregating Species protection	Biodiversity protection	Fisheries impacts	Enforcement
Spatial closure (FSA sites)	Good if FSA is highly predictable in space and time, where no increase in total annual mortality will occur (fishing effort redistribution), and when on-water enforcement is good	Effective especially if multi-species FSA	Depends on size and productivity of area and proximity to port	Requires vessel patrols, radar, or VMS year round.
Temporal closures (Target species)	Good for FSA's without predictable locations or with potential for substantial movement across closure boundaries (such as defined migration corridors), or when on-water enforcement is poor	Much less effective, only indirect result of target species protection	Worst for target fishery, possibly less impact for multi-species fisheries	Some patrolling, checkpoints at sites of delivery, possession checks
Spatio-temporal closure (Target species FSA site)	Good for FSA's with a mix of substantial target species movement, spatial enforcement issues, where poaching may be likely, and where overall fishing mortality is not a concern	Less effective	Least impact if closure is small and/or short	Requires vessel patrols, radar, or VMS during closure

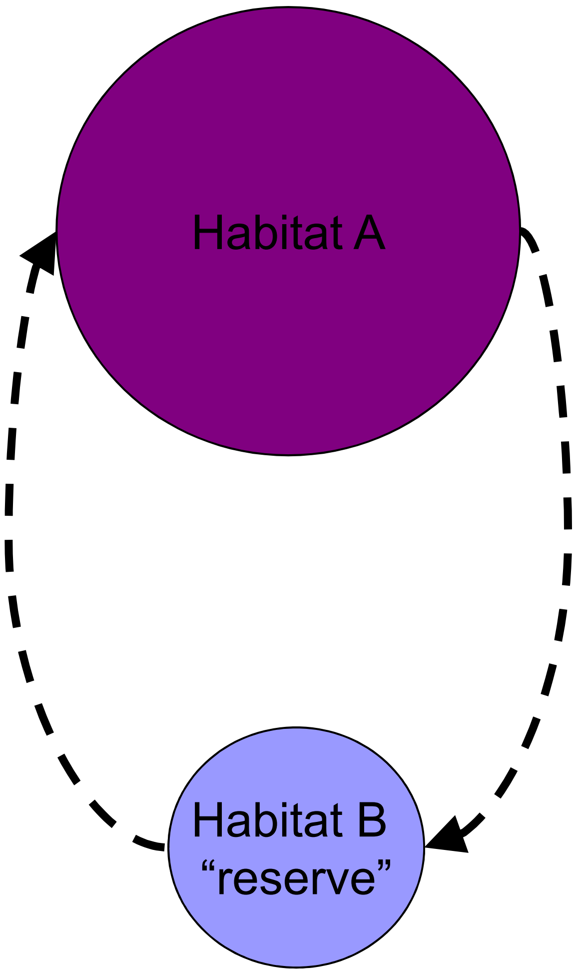
Grüss et al. in prep
Conservation and fisheries effects of spawning aggregation-based MPAs
Rev. Fish and Fisheries



Metapopulation models

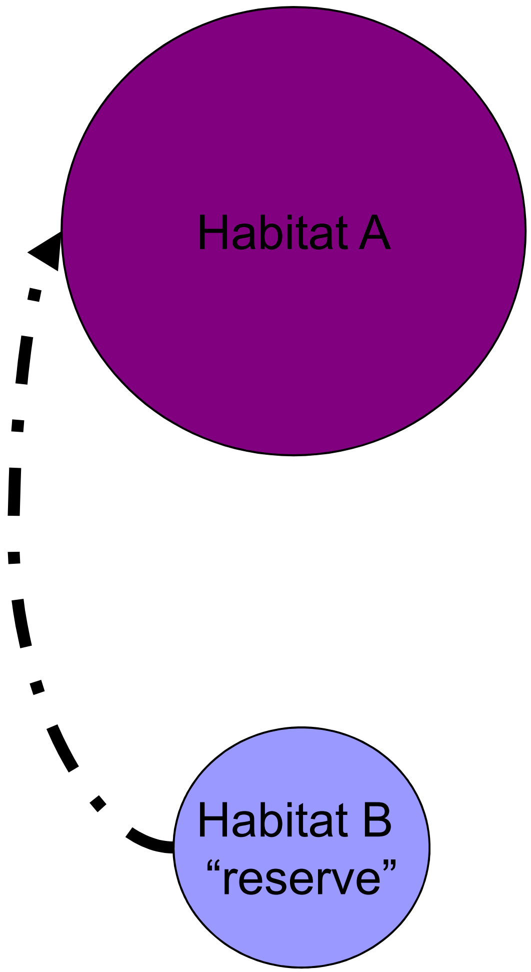


Types of movement



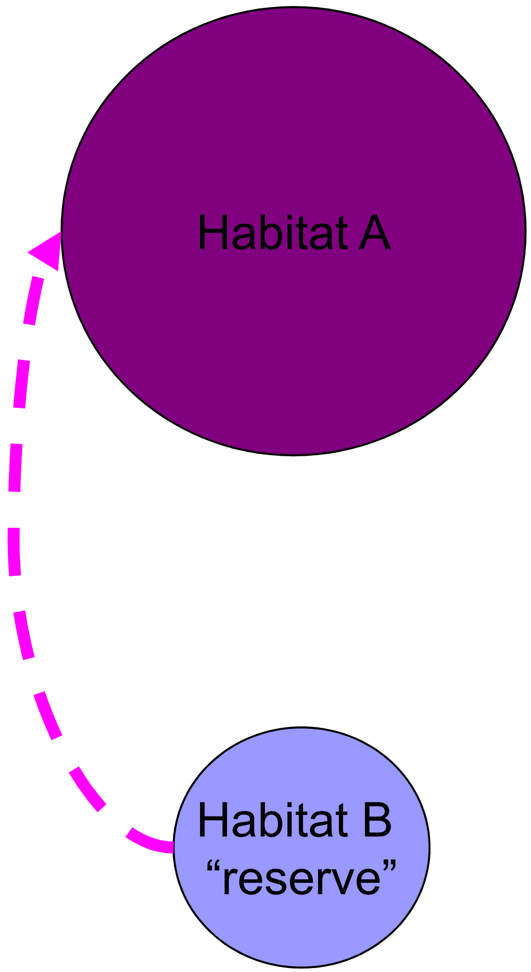
“Leaking” = stochastic movement (random)

Types of movement



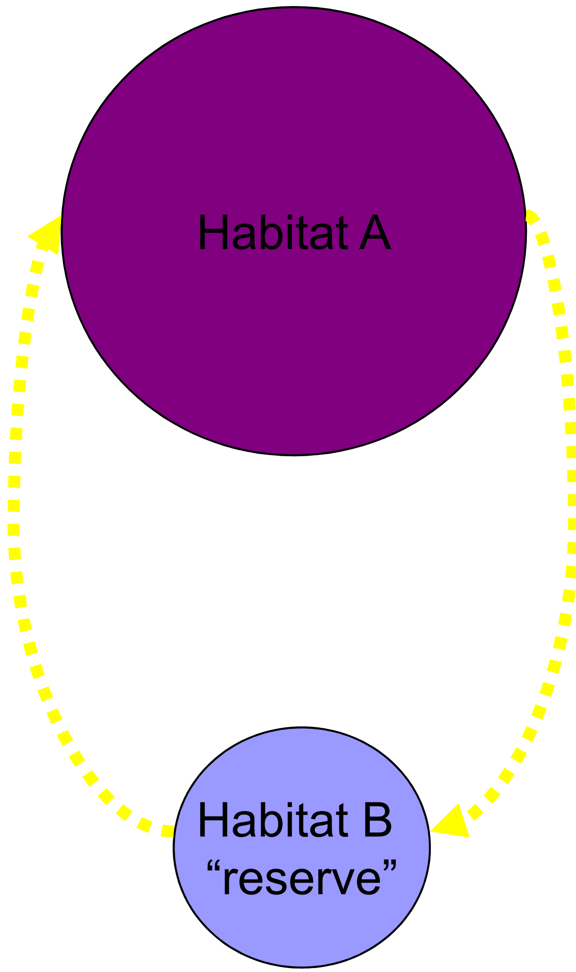
“spill-over” = density-dependent leaking

Types of movement

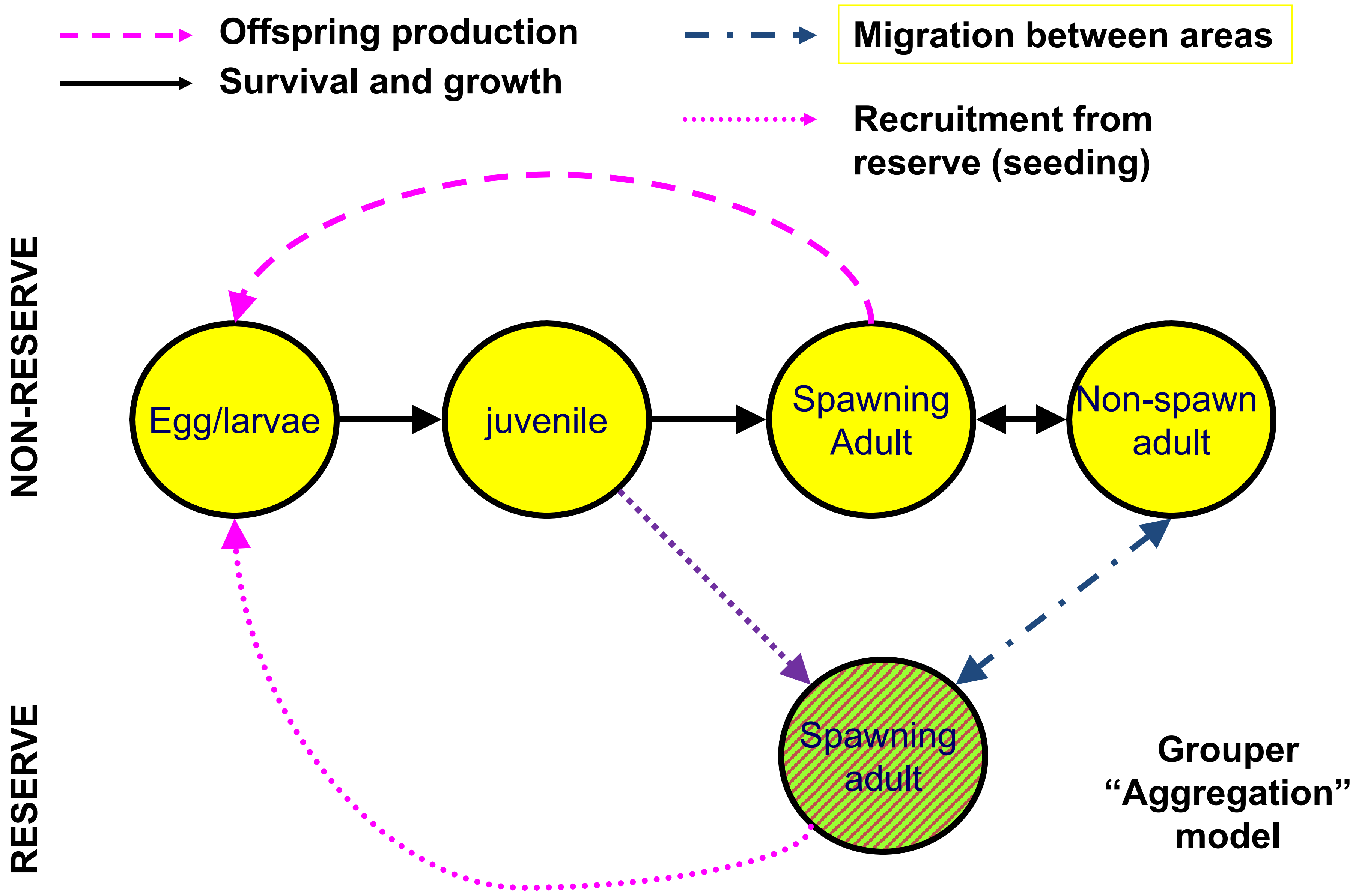


“seeding” = larval transport

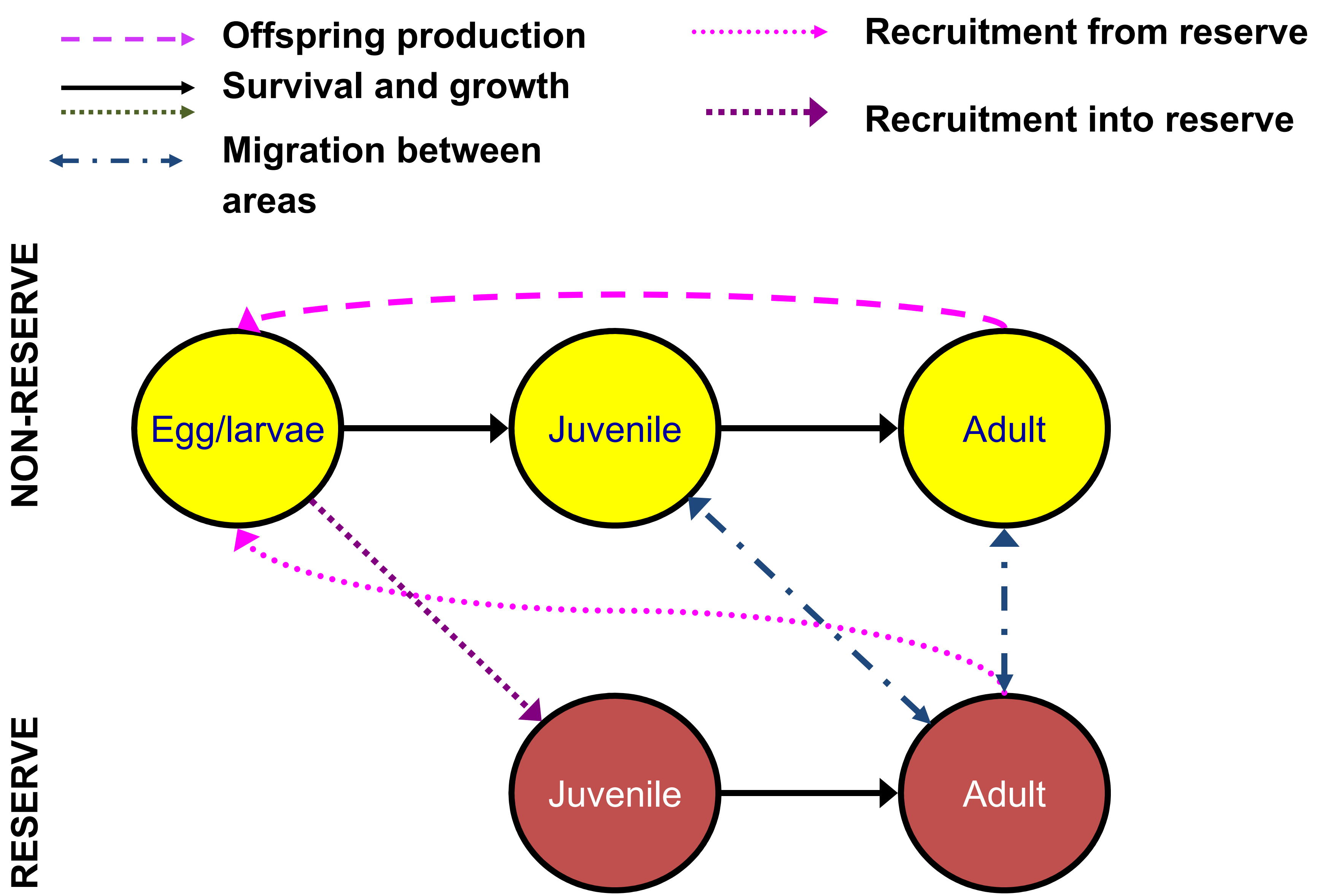
Types of movement



“ontogenetic shift” = deterministic (directed) movement between habitats due to life stage transition

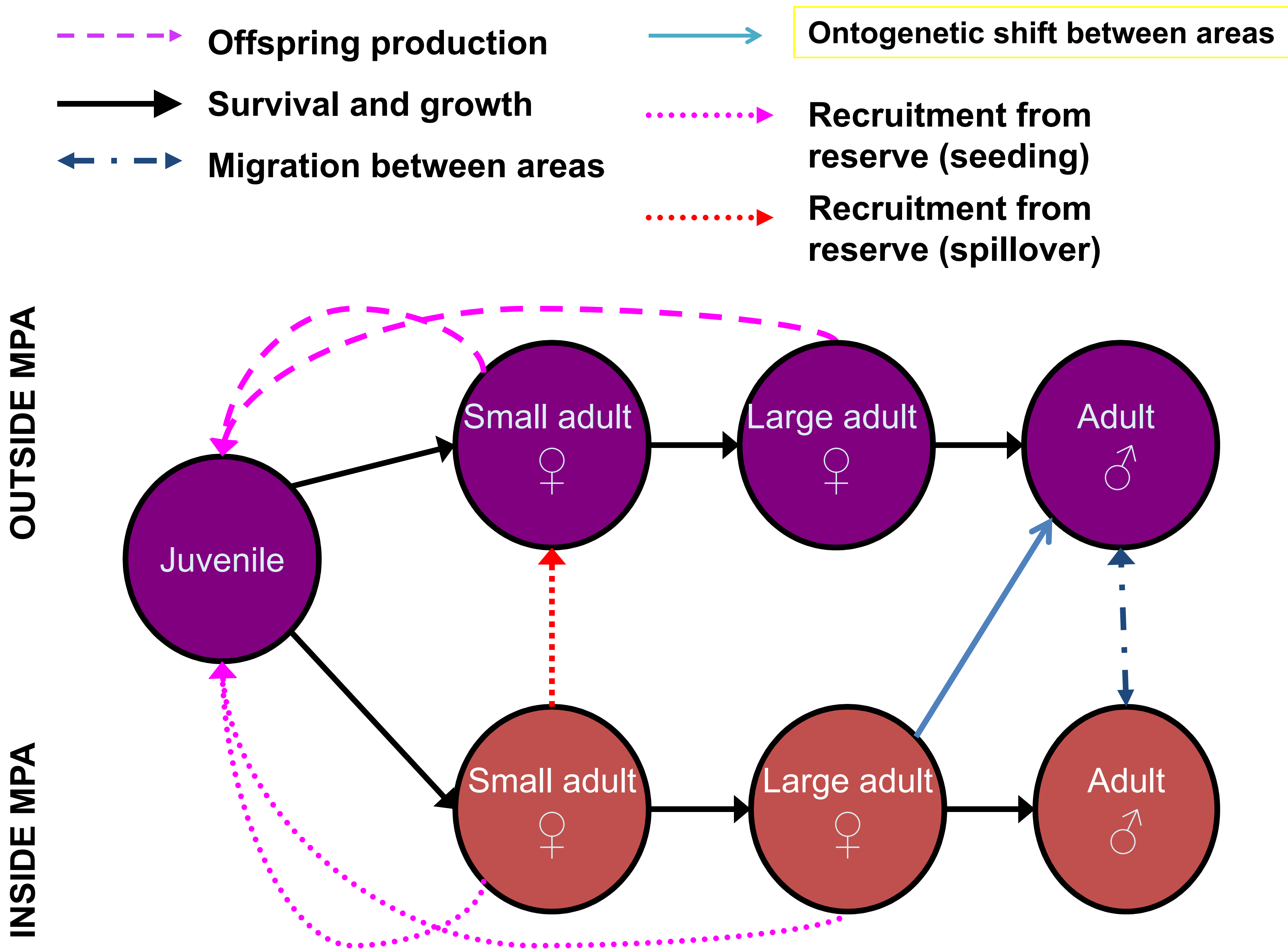


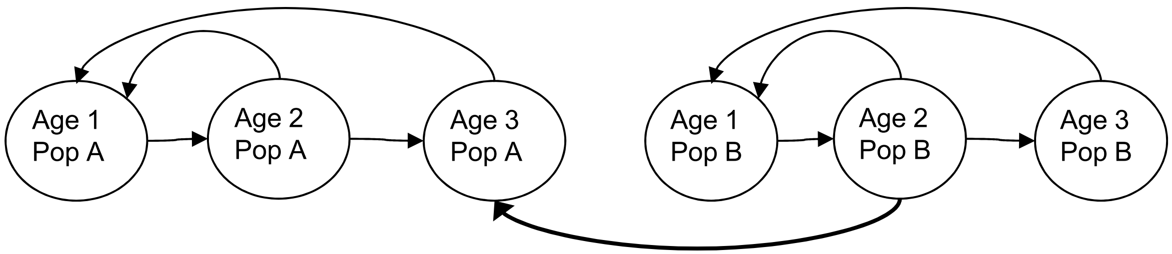
Adult Reserve



Life history network model

Reserve protects both juveniles and adults ← **Need 2 matrices**


Offspring production
Survival and growth
Migration between areas
Ontogenetic shift between areas
Recruitment from reserve (seeding)
Recruitment from reserve (spillover)
OUTSIDE MPA
INSIDE MPA
Juvenile
Small adult ♀
Large adult ♀
Adult ♂
Small adult ♀
Large adult ♀
Adult ♂



		Pop A age 1	Pop A age 2	Pop A age 3	Pop B age 1	Pop B age 2	Pop B age 3
	Pop A age 1	0	1	1	0	0	0
	Pop A age 2	0.5	0	0	0	0	0
META =	Pop A age 3	0	0.7	0	0	0.12	0
	Pop B age 1	0	0	0	0	1.6	1.6
	Pop B age 2	0	0	0	0.5	0	0
	Pop B age 3	0	0	0	0	0.48	0