# Supporting information

# Ocean Futures as Explored Using a Worldwide Suite of Ecosystem Models

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**Table S1.** Total model area closed in the spatial management scenarios and functional groups (with name codes) affected in the ocean acidification and fisheries management scenarios.

| **Model** | **MPA closures** | **Ocean acidification** | **Fisheries management** |
|---|---|---|---|
| California Current | 10% MPA =9,299 km2<br>25% MPA = 23,805 km2<br>50% MPA = 53,852 km2 | Stony corals (TCR), Black corals (BCR), Shallow (BFS), Bivalves (BFF), Benthic grazers (BG), Nearshore urchins (NUR), BMD (Sea stars), Coccolithophores (COC) | Harvested Invertebrates: Deposit feeders (BD), Bivalves (BFF), Benthic herbivorous grazers (BG), Nearshore sea urchins (NUR), Pandalid shrimp (PSP), Crangon shrimp (PWN), Crabs (BML), Dungeness crab (DUN), Squid (CEP), Market squid (MSQ), Humboldt squid (HSQ)<br><br>Small pelagics: Mackerel (FPL), Jack mackerel (JAC), Small planktivorous fish (FPS), Sardines (SAR), Anchovies (ANC), Pacific herring (HER)<br><br>Demersal fish and sharks: Dover sole (FDP), Canary rockfish (FPO), Shortbelly rockfish (FVV), Yelloweye rockfish (YEL), Deep demersal fish (FDD), Deep small rockfish (FDC), Deep large rockfish (FDO), Darkblotched rockfish (DAR), Small flatfish (FDF), Shallow miscellaneous fish (FDE), Midwater rockfish (FDS), Bocaccio (BOC), Pacific Ocean perch (POP), Shallow small rockfish (FDB), Shallow large rockfish (SHR), Pacific hake (FMM), Sablefish (FMN), Large piscivorous flatfish (FVD), Arrowtooth flounder (ARR), Petrale sole (PET), Large demersal predators (FVS), Demersal sharks (SHD), Small demersal sharks (SHB), Spiny dogfish (DOG), Skates and rays (SSK)<br><br>Large pelagic and Highly migratory species: Large pelagic predators (FVT), Pelagic sharks (SHP) |
| Guam | 14% MPA = 25.6 $km^2$<br>25% MPA = 37.4 $km^2$<br>50% MPA = 61.3 $km^2$ | Branching corals (CRS), Massive corals (CRN), Crustose coralline algae (CCA), Benthic carnivores (BC), Bivalves (BFF), Benthic grazers (BG), Sea stars (BSS), Coccolithophores (PS) | Harvested Invertebrates:<br>Benthic filter feeders (BFF), Benthic grazers (e.g. urchins; BG), Octopi (CEP), Deposit feeders (e.g. sea cucumbers, lobster, crab; BD), Benthic carnivores (snails, crabs; BC)<br><br>Small pelagics:<br>Mid-water piscivore (FPM), Roving piscivore (e.g. jacks; FPR)<br><br>Demersal fish and sharks:<br>Planktivores (FPL), Benthic piscivores |

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| | | | (e.g. groupers; TPB, FPB), Herbivore browsers (e.g. Chubs; THB, FHB), Bumphead parrotfish (BHP), Herbivore excavators (large-bodied parrotfishes; FHE), Herbivore Scrapers (small-bodied parrotfishes; FHS), Herbivore grazers (surgeonfishes; THG, FHG), Humphead wrasse (HHW), Invertivores (e.g. goatfish, snappers; TIV; FIV), Detritivores (FDE), Sting ray (RAY), Reef-associated sharks (SHR)<br><br>Large pelagic and Highly migratory species:<br>NONE |
| Northern Gulf of California | 10% MPA = 32.2 km2<br>25% MPA = 81.7 km2<br>50% MPA = 160.3 km2 | Bivalves (BMS), Scallops (BC), Snails (BO), Herbivorous echinoderms (BG), Sea cucumbers (BFD), Carnivorous macrobenthos (BMD), Sessile invertebrates (BFF), Macroalgae (MA) | Harvested invertebrates<br>Adult blue crab (CEP), Crabs and lobsters (BFS), Sessile invertebrates (BFF), Sea cucumbers (BFD), Herbivorous echinoderms (BG), Carnivorous macrobenthos (BMD), Meiobenthos (BML), Bivalves (BMS), Adult blue shrimp (PWN), Jellyfish (ZG), Scallops and penshells (BC), Squid (ZM), Snails (BO)<br><br>Small pelagics:<br>Small pelagics (SSK)<br><br>Demersal fish and sharks:<br>Small demersal fish (FPL), Pacific Angel shark (FPS), Guitarfish (FVD), Flatfish (FVS), Skates rays and sharks (FVO), Scorpionfish (FVV)<br><br>Large pelagic and Highly migratory species:<br>Large pelagics (SHD), Seabirds (SB), Mysticetes (WHB), Large pelagic sharks (FVB), Oceanic turtles (SP), Reef associated turtles (REP), Small migratory sharks (FPO) |
| Chesapeake Bay | 10% closure = 890 km2<br>25% closure = 2,224 km2<br>50% closure = 4,448 km2 | Benthic filter feeders (BFD), Oysters (BFF), *Macoma spp.*(BFS) | Harvested invertebrates:<br>oysters (BFF), blue crab (PWN)<br><br>Small pelagic fish:<br>Atlantic silversides and mummichog (FDP), Atlantic menhaden (FPS), Butterfish and harvestfish (FMN), Shad and herring (FMM)<br><br>Demersal fish and sharks:<br>Summer flounder (FVD), Other flatfish (FDF), catfish (FVB), Spotted hake, lizard fish, and northern sea robin(FDC), Atlantic croaker (FDD), White perch (FDS), Spot, silver perch, yellow perch, and bluegill (FDE), Atlantic spadefish, |

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| | | | tautog, black seabass, toadfish (FDM), Smooth dogfish (SHB), Sandbar shark (SHD), Spiny dogfish (SHC), Cownose ray (SSK)<br><br>Large pelagic and Highly migratory species:<br>Bluefish (FVT), Striped bass (FBP), Smooth dogfish (SHB), Sandbar shark (SHD), Spiny dogfish (SHC), Cownose ray (SSK) |
| Nordic and Barents Sea | 10% closure = 249761 km2<br>25% closure = 379682 km2<br>50% closure = 657400 km2 | Snow crab (SCR) , Red king crab (KCR), Carnivore benthos (BC), Detritivore benthos (BD), Benthic filter feeders (BFF), Corals (COR) | Demersal fish: Northeast arctic cod (NCO), Greenland halibut (GRH), Saithe (SAI), Haddock (HAD), Beaked redfish (RED), Golden redfish (REO). Note for these species we assume Base Case scenario has F= $F_{MSY}$.<br><br>Small pelagics: capelin (CAP)<br><br>Harvested invertebrates: not tested<br><br>Large pelagic and Highly migratory species:<br>NONE |
| Gulf of Mexico | 10% closure = 56,420 km2<br>25% closure = 141,050 km2<br>50% closure = 282,100 km2 | Stony corals (COR), Crustose coralline algae (CCA), Octocorals (OCT), Carnivorous macrobenthos (CMB), Herbivorous echinoderms (ECH), Oysters (OYS), Bivalves (BIV), Small phytoplankton (SPP) | Harvested Invertebrates:<br>Brown shrimp (BSH), White shrimp (WSH), Pink shrimp (PSH), Other shrimp (OSH), Blue crab (BCR), Stone crab (SCR), Crabs and lobsters (LOB), Stony corals (COR), Crustose coralline algae (CCA), Octocorals (OCT), Sponges (SPG), Carnivorous macrobenthos (CMB), Infaunal meiobenthos (INF), Herbivorous echinoderms (ECH), Oysters (OYS), Bivalves (BIV), Sessile filter feeders (SES), Jellyfish (JEL), Squid (SQU)<br><br>Small pelagics:<br>Ladyfish (LDY), Spanish sardine (SAR), Menhaden (MEN), Pinfish (PIN), Small pelagic fish (SPL)<br><br>Demersal fish and sharks:<br>Gag grouper (GAG), Red grouper (RGR), Scamp (SCM), Shallow serranidae (SSR), Deep serranidae (DSR), Red snapper (RSN), Vermilion snapper (VSN), Lutjanidae (LUT), Bioeroding fish (BIO), Large reef fish (LRF), Small reef fish (SRF), Black drum (BDR), Red drum (RDR), Seatrout (SEA), Sciaenidae (SCI), Mullets (MUL), Sheepshead (SHP), Flatfish (FLT), Other demersal fish (ODF), Small demersal fish (SDF), Deep water fish (DWF), |

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| | | | Benthic feeding sharks (BEN), Skates and rays (RAY)<br><br>Large pelagic and Highly migratory species:<br>Pompano (POM), Snook (SNK), Yellowfin tuna (YTN), Bluefin tuna (BTN), Little tunny (LTN), Other tuna (OTN), Swordfish (SWD), White marlin (WMR), Blue marlin (BMR), Other billfish (BIL), Greater amberjack (AMB), Jacks (JCK), King mackerel (KMK), Spanish mackerel (SMK), Large pelagic fish (LPL), Medium pelagic fish (MPL), Blacktip shark (TIP), Large sharks (LGS), Filter feeding sharks (FIL), Small sharks (SMS) |
| Northeast USA | 10% closure = 26,400 km2<br>25% closure = 66,000 km2<br>50% closure = 132,000 km2 | Sea scallop (BFS), Benthic carnivore (BC), Other benthic filter feeder (BFF), Benthic grazer (BG) | Harvested invertebrates: Squid (CEP), Sea scallop (BFS), Other benthic filter feeders (BFS), Benthic grazers (BG), Lobster (BML), Shallow macrozoobenthos (BMS), Shrimp (PWN), Deposit feeders (BD)<br><br>Small pelagics: Atlantic mackerel (FPL), Atlantic herring (FPS), Migratory mesopelagics (FMM), Benthopelagic fish (FBP), Shallow demersal fish (FDE)<br><br>Demersal fish and sharks: White hake (FVD), Other piscivores (FVB), Goosefish (FDD), Atlantis cod (FDS), Silver hake (FDB), Miscellaneous demersal fish (FDC), Haddock (FDO), Yellowtail flounder (FDF), Spiny dogfish (SHB), Other demersal sharks (SHD), Skates and rays (SSK)<br><br>Large pelagic and Highly migratory species: Large piscivores (FVT), Pelagic sharks (SHP) |
| SE Australia | 10% closure = 51,085 km2<br>25% closure = 164,110 km2<br>50% closure = 275,540 km2 | Scallops (BFS), Shallow water filter feeders (BFF), Deep water filter feeders (BFD), Herbivorous grazers (BG) | Harvested Invertebrates: Shallow water filter feeders (BFF), Scallops (BFS), Herbivorous grazers (BG), Shallow water megazoobenthos (BMS),<br>Rock lobster (BML), Prawns (PWN), Squid (CEP)<br><br>Small pelagics: Sardine (FPS), Anchovy (FPA), Redbait (FBP), Blue mackerel (FPM), Jack mackerel (FPL)<br><br>Demersal fish and sharks: School whiting (FVO), shallow water piscivores (FVS), Blue warehou (SP), Spotted warehou (FVB), shallow water demersal fish (FDS), Flahtead (FDB), Redfish (FDM), Morwong (FPO), Pink ling (FDC), Blue grenadier (FDE), Blue-eye trevalla |

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| | | | (FDF), Ribaldo (FDP), Orange roughy (FDO), Dories and oreos (FDD), Cardinalfish (FVD), Gummy shark (SHB), School shark (SHR), Dogfish (SHC), Skates and Rays (SSK), Demersal sharks (SHD), Gulper sharks (REP)<br><br>Large pelagic and Highly migratory species: Tuna and billfish (FVT), Gemfish (FVV), large pelagic sharks (SHP) |

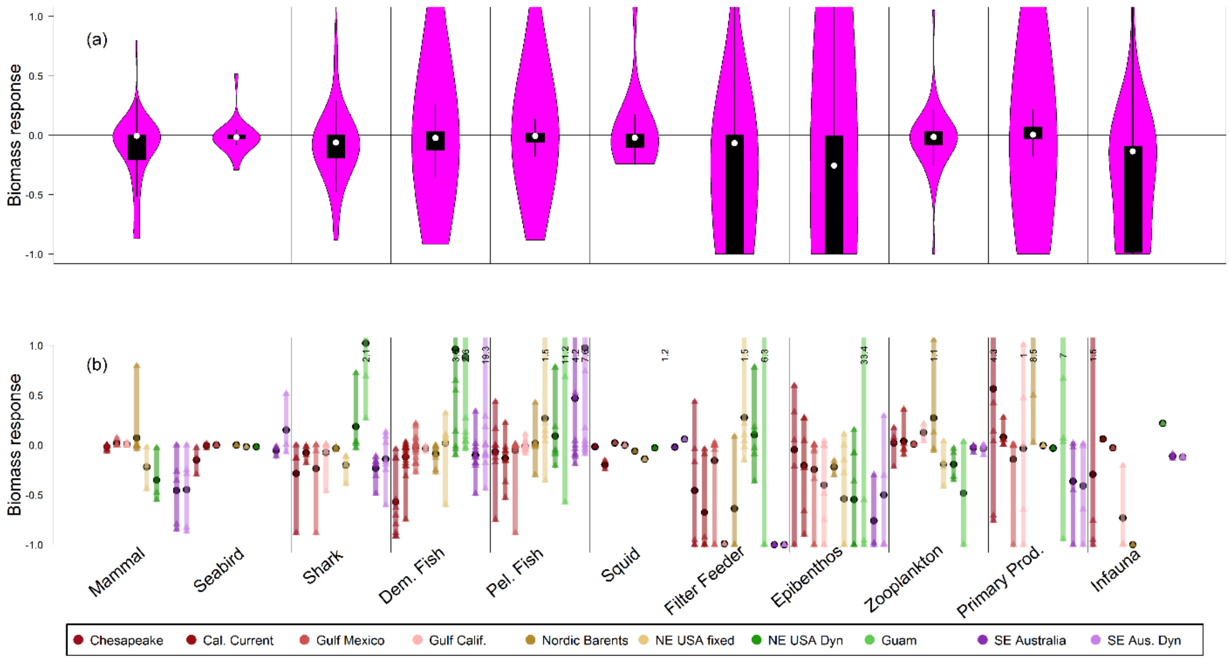


***Fig S1. Biomass response of fifty-year scenarios of ocean acidification, via an additional 0.5% (day$^{-1}$) mortality rate added for selected groups. Top panel: The shape of the violin plots shows the kernel density of biomass responses across all individual functional groups in all models. Superimposed box plots illustrate the median (white), 5th and 95th percentiles (lines) and first and third quartile (boxes). Functional group responses which exceed 1.0 (i.e., doubling of biomass and the limit of the y-axis) are truncated here but noted in the lower panel. Lower panel: Detailed results, with each ecosystem model represented by a unique color. Vertical bars represent the range of functional group responses, grouped by guilds, within each ecosystem model. Small triangles are individual functional group responses, and black circles are the average responses per model. Functional group responses which exceed y-value of 1.0 (i.e., doubling of biomass) are indicated by black text.***

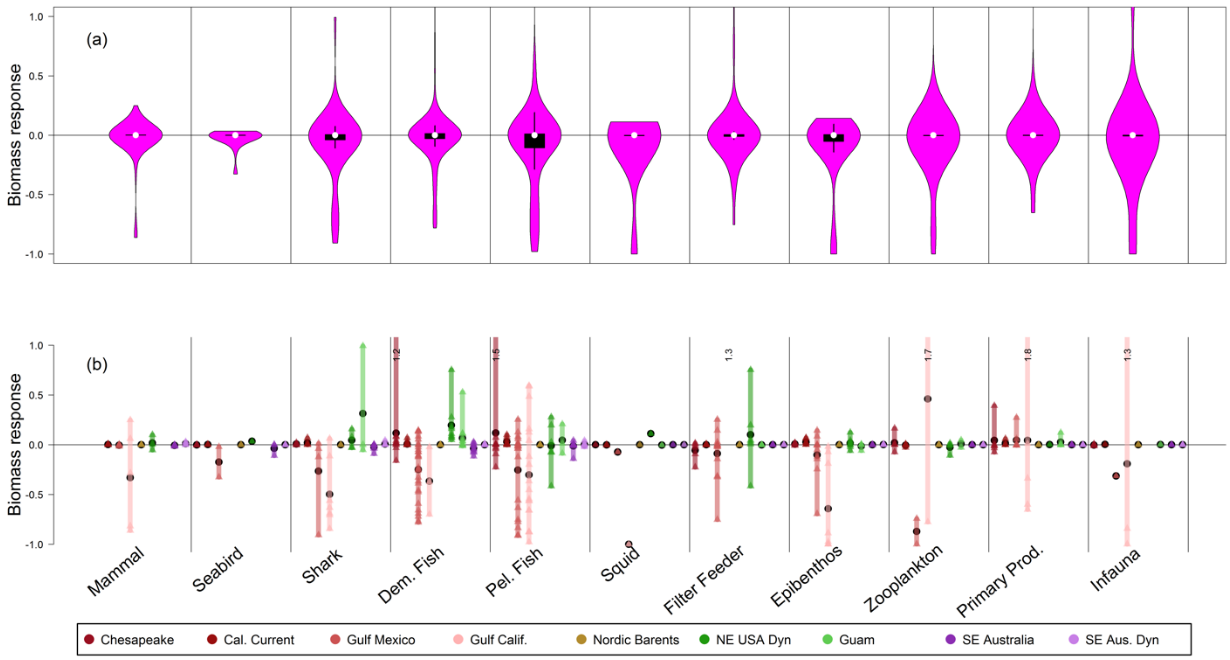


***Fig S2. As in Figure S1, but representing biomass response of fifty-year scenarios of spatial management closing 10% of continental shelf (<250m depth) to fishing.***

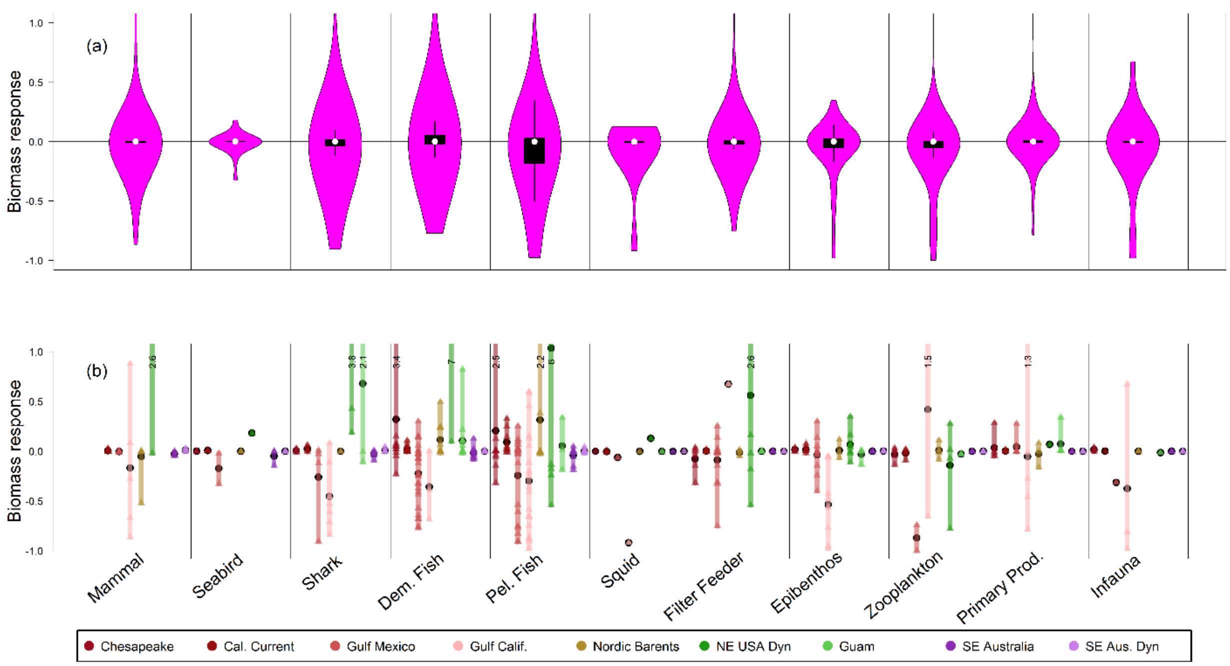


***Fig S3. As in Figure S1, but representing biomass response of fifty-year scenarios of spatial management closing 25% of continental shelf (<250m depth) to fishing.***

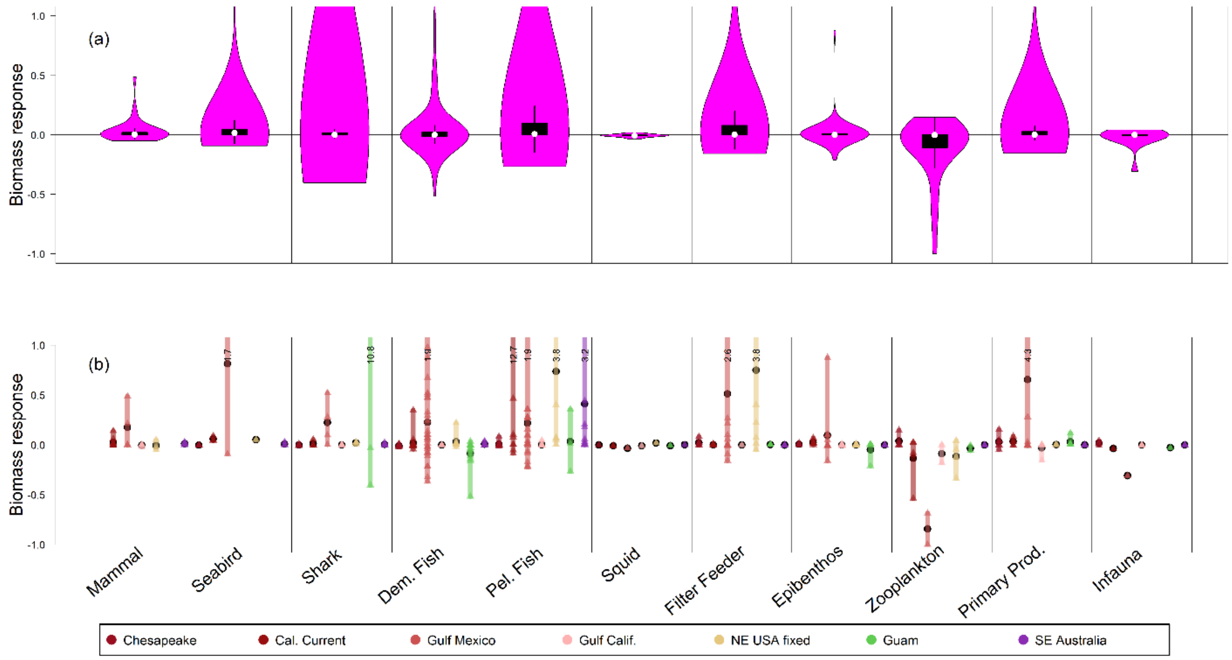


***Fig S4. As in Figure S1, but representing biomass response of fifty-year scenarios with no fishing mortality on small pelagic fish.***

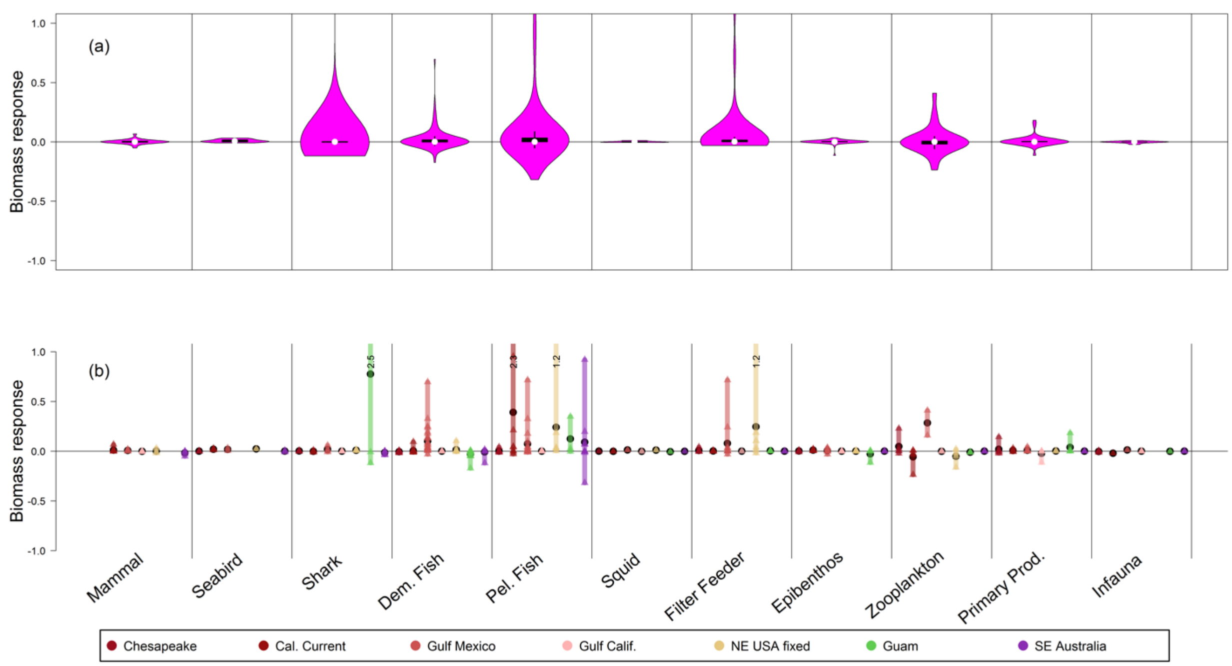


***Fig S5. As in Figure S1, but representing biomass response of fifty-year scenarios with 0.5x fishing mortality on small pelagic fish.***

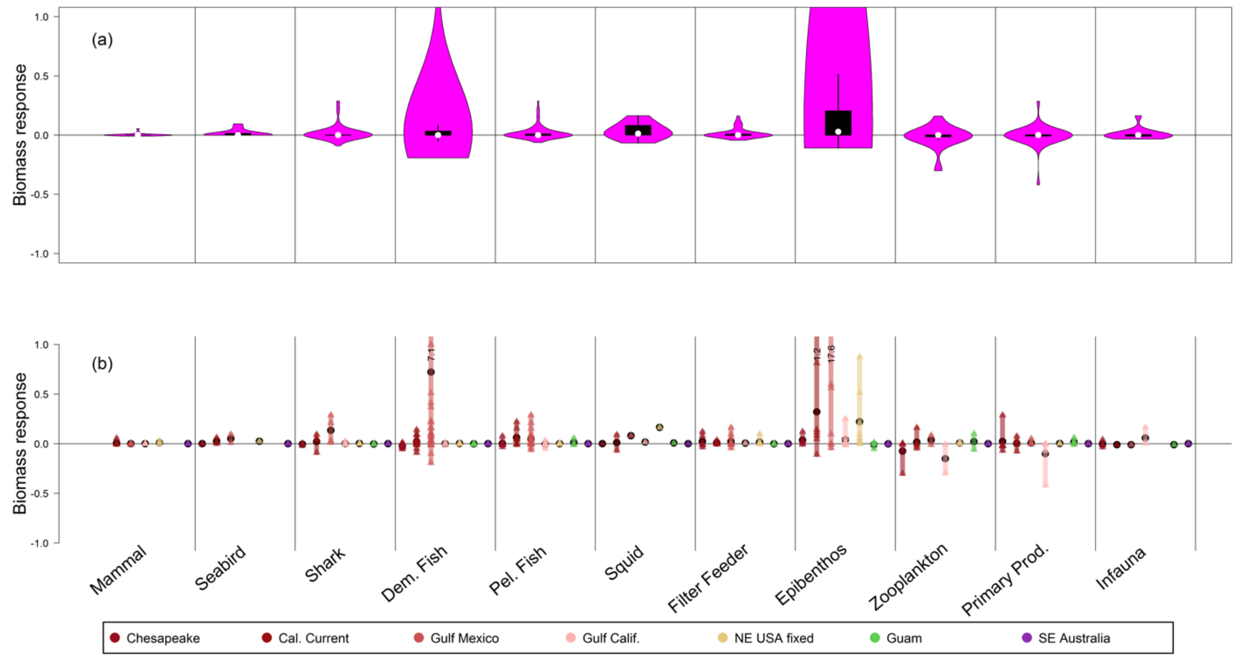


***Fig S6. As in Figure S1, but representing biomass response of fifty-year scenarios with 0x fishing mortality on invertebrates.***

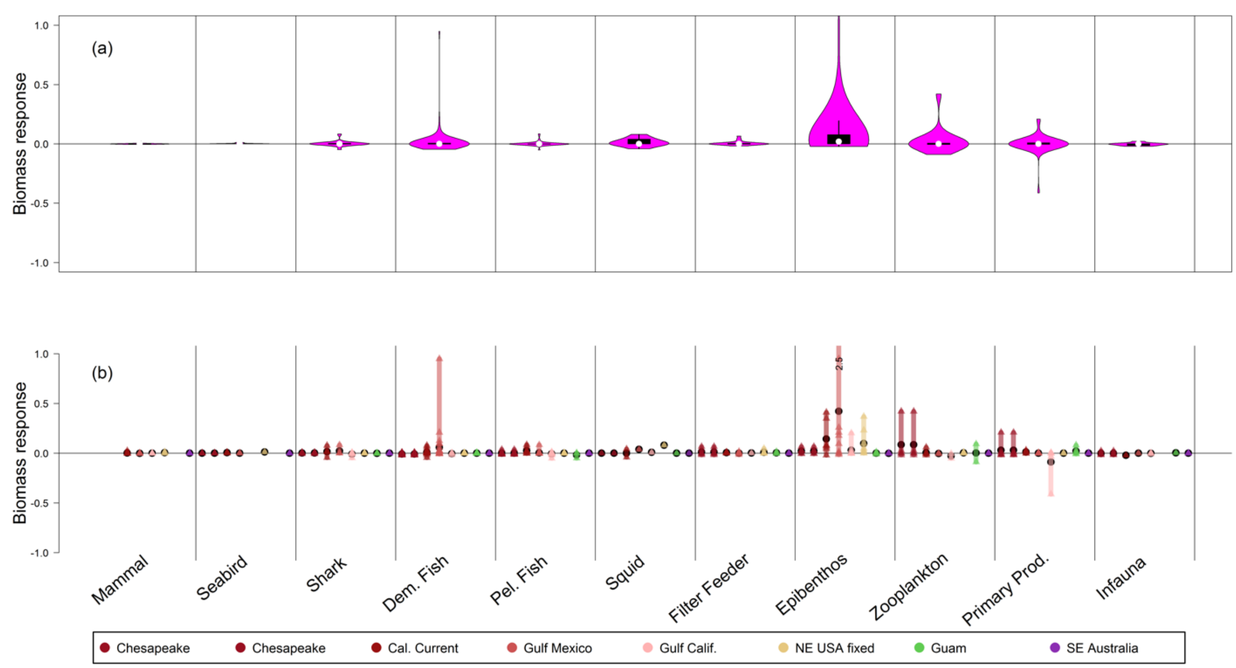


***Fig S7. As in Figure S1, but representing biomass response of fifty-year scenarios with 0.5x fishing mortality on invertebrates.***

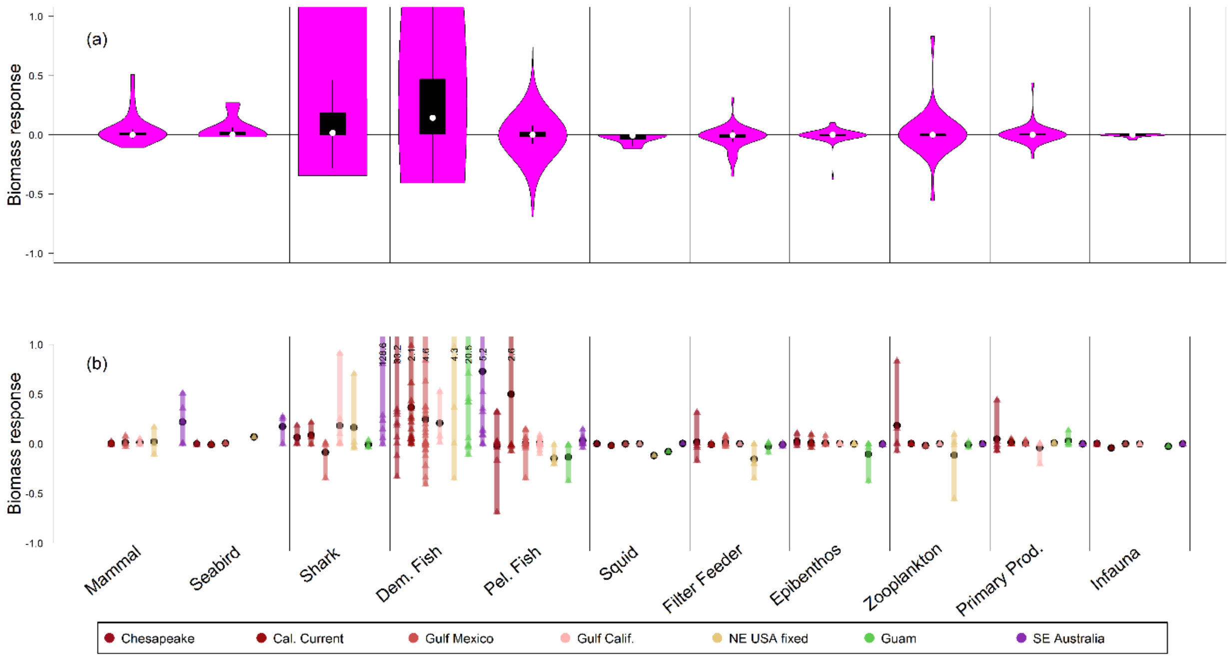


***Fig S8. As in Figure S1, but representing biomass response of fifty-year scenarios with 0x fishing mortality on demersal fish.***

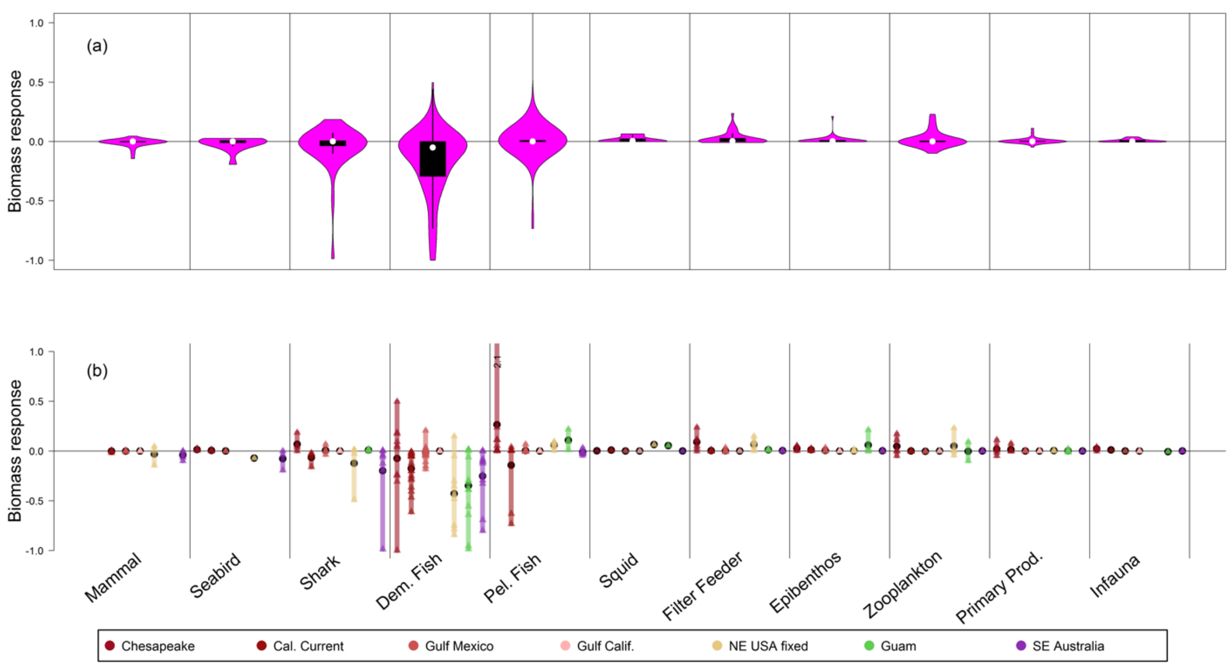


***Fig S9. As in Figure S1, but representing biomass response of fifty-year scenarios with 2x fishing mortality on demersal fish.***

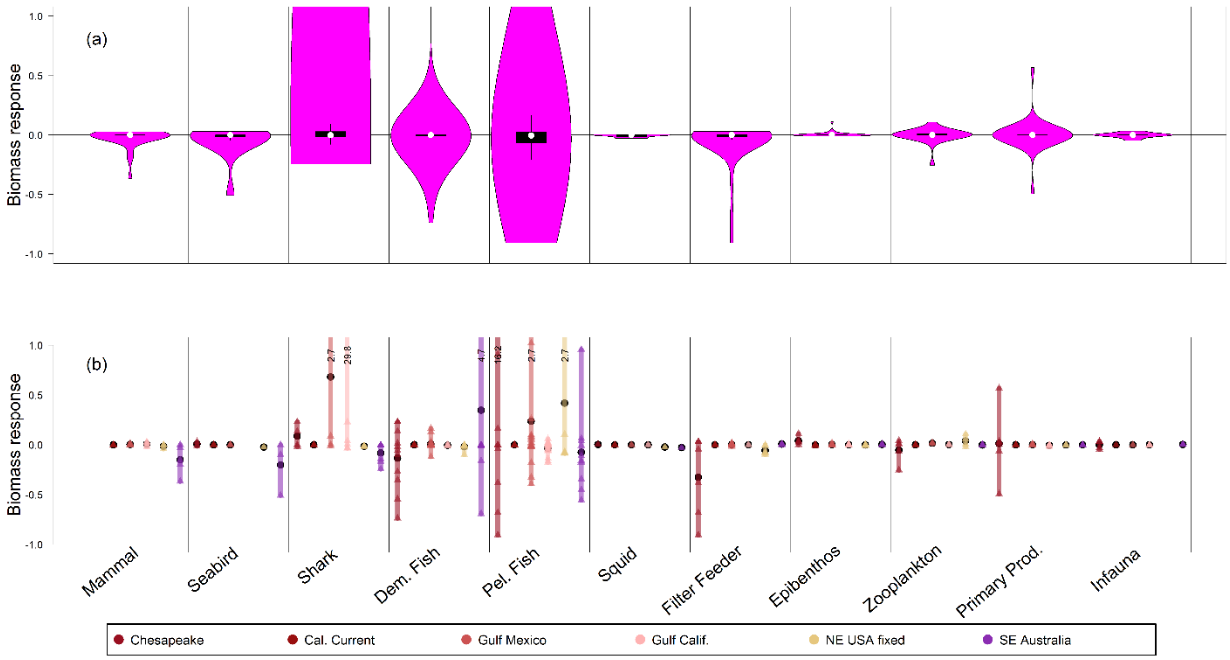


***Fig S10. As in Figure S1, but representing biomass response of fifty-year scenarios with 0x fishing mortality on large pelagic fish.***

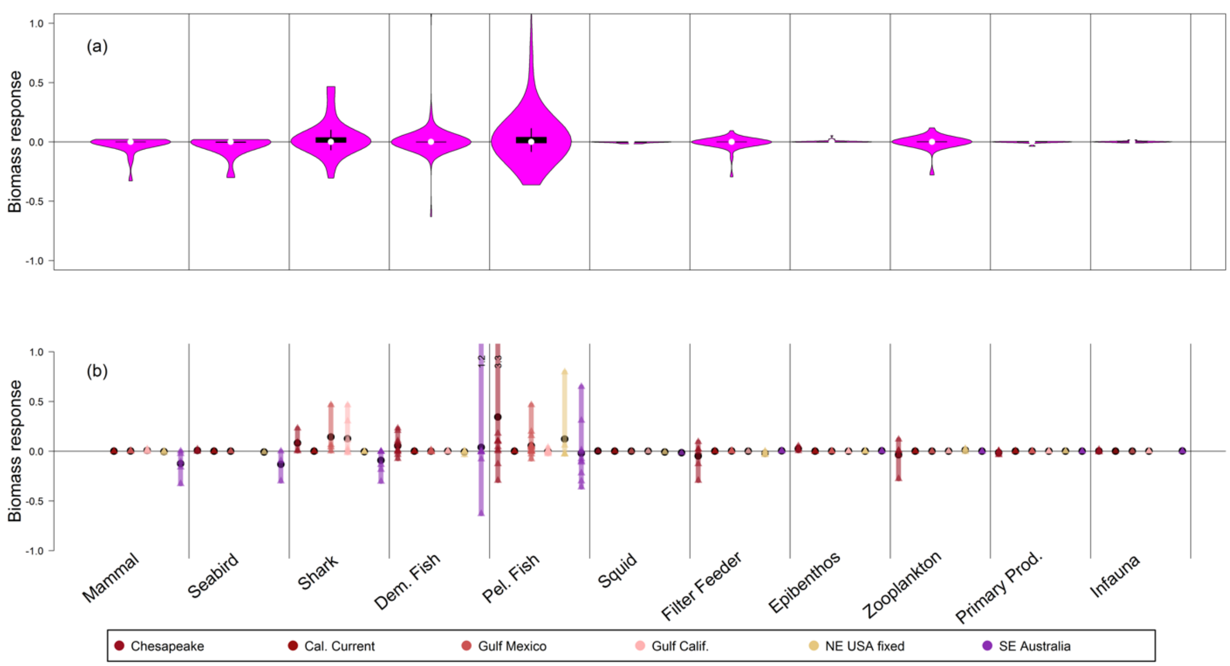


***Fig S11. As in Figure S1, but representing biomass response of fifty-year scenarios with 0.5x fishing mortality on large pelagic fish.***

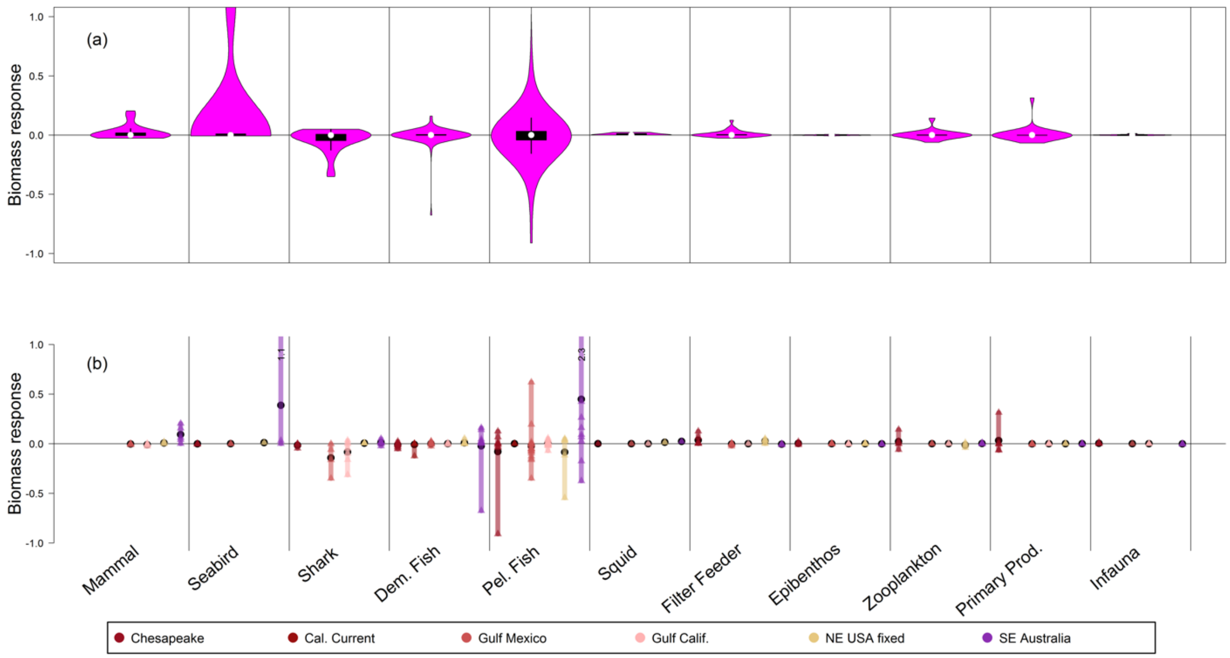


***Fig S12. As in Figure S1, but representing biomass response of fifty-year scenarios with 2x fishing mortality on large pelagic fish.***

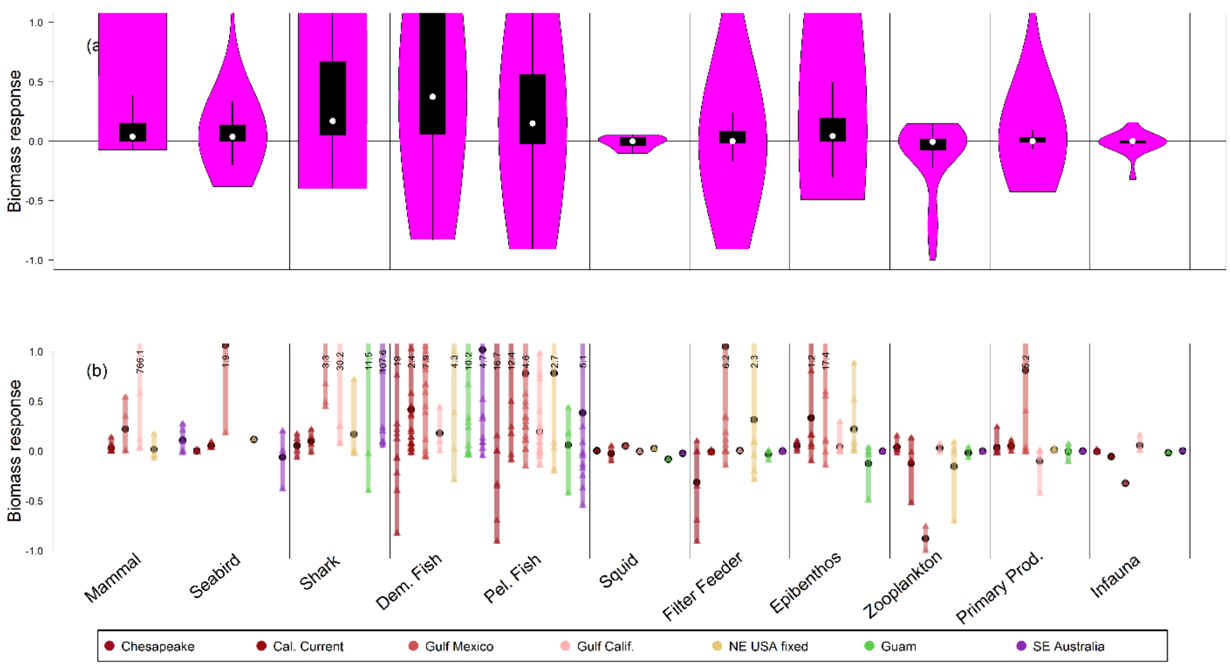


***Fig S13. As in Figure S1, but representing biomass response of fifty-year scenarios with no fishing mortality on any group.***

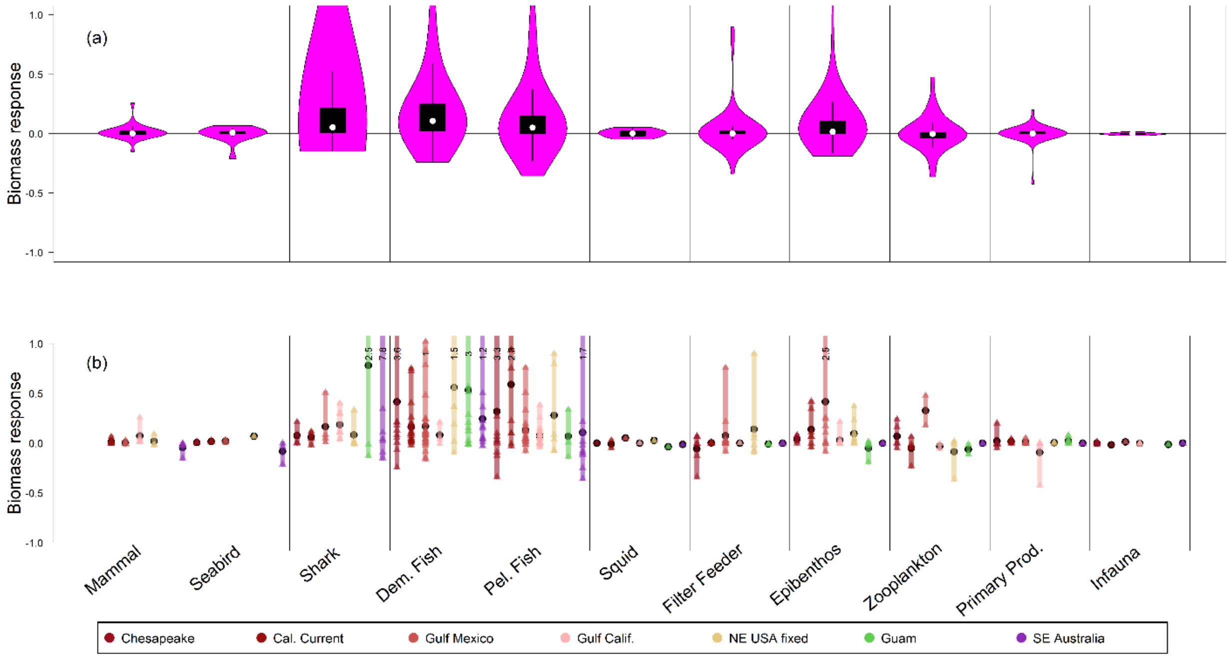


*Fig S14.* ***As in Figure S1, but representing biomass response of fifty-year scenarios with 0.5x fishing mortality on all groups.***

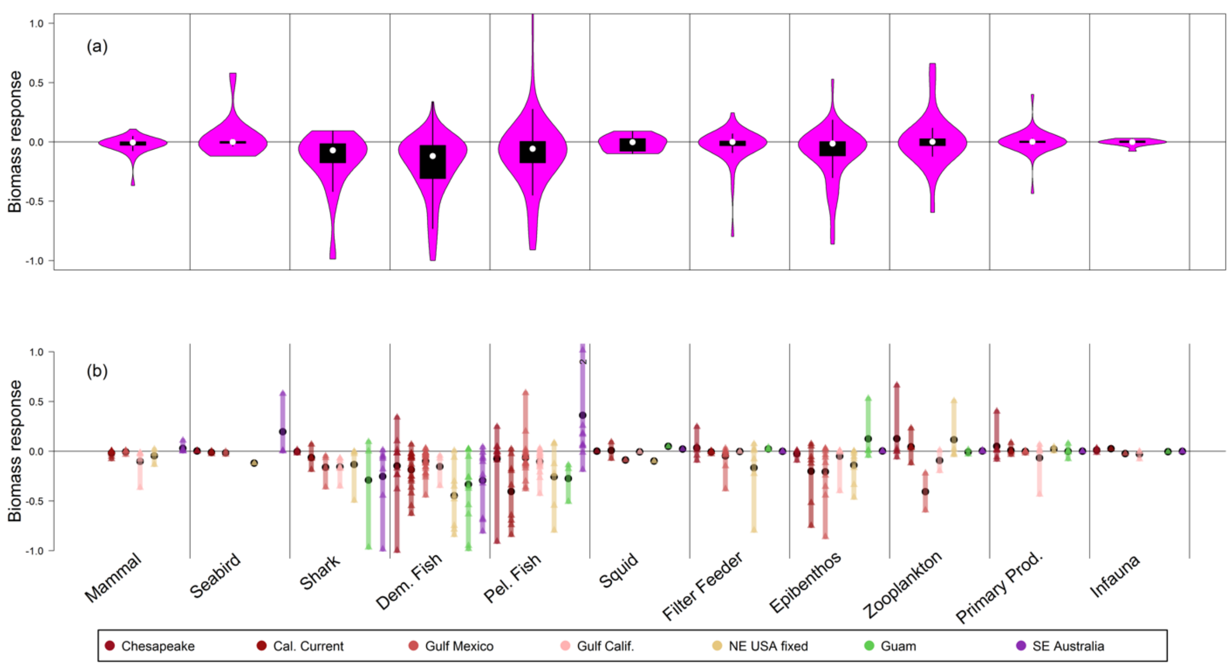


***Fig S15. As in Figure S1, but representing biomass response of fifty-year scenarios with 2x fishing mortality on all groups.***

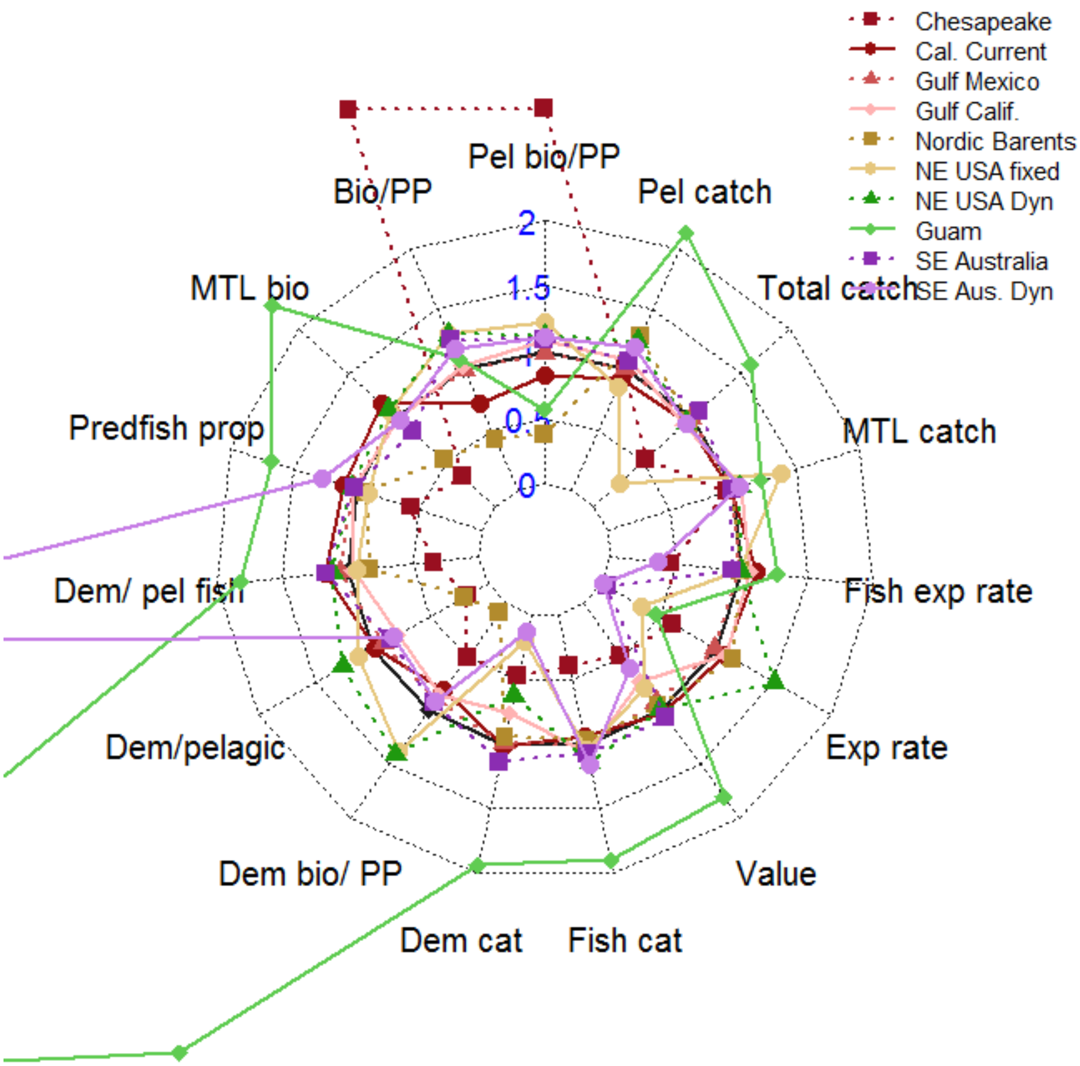


***Fig S16. Ecological and Fishery metrics for scenarios of ocean acidification, via an additional 0.5% ($day^{-1}$) mortality rate added for selected groups. Metrics are generally ordered by: Ecological metrics (left), fishery metrics (right), pelagic (top), demersal (bottom).***

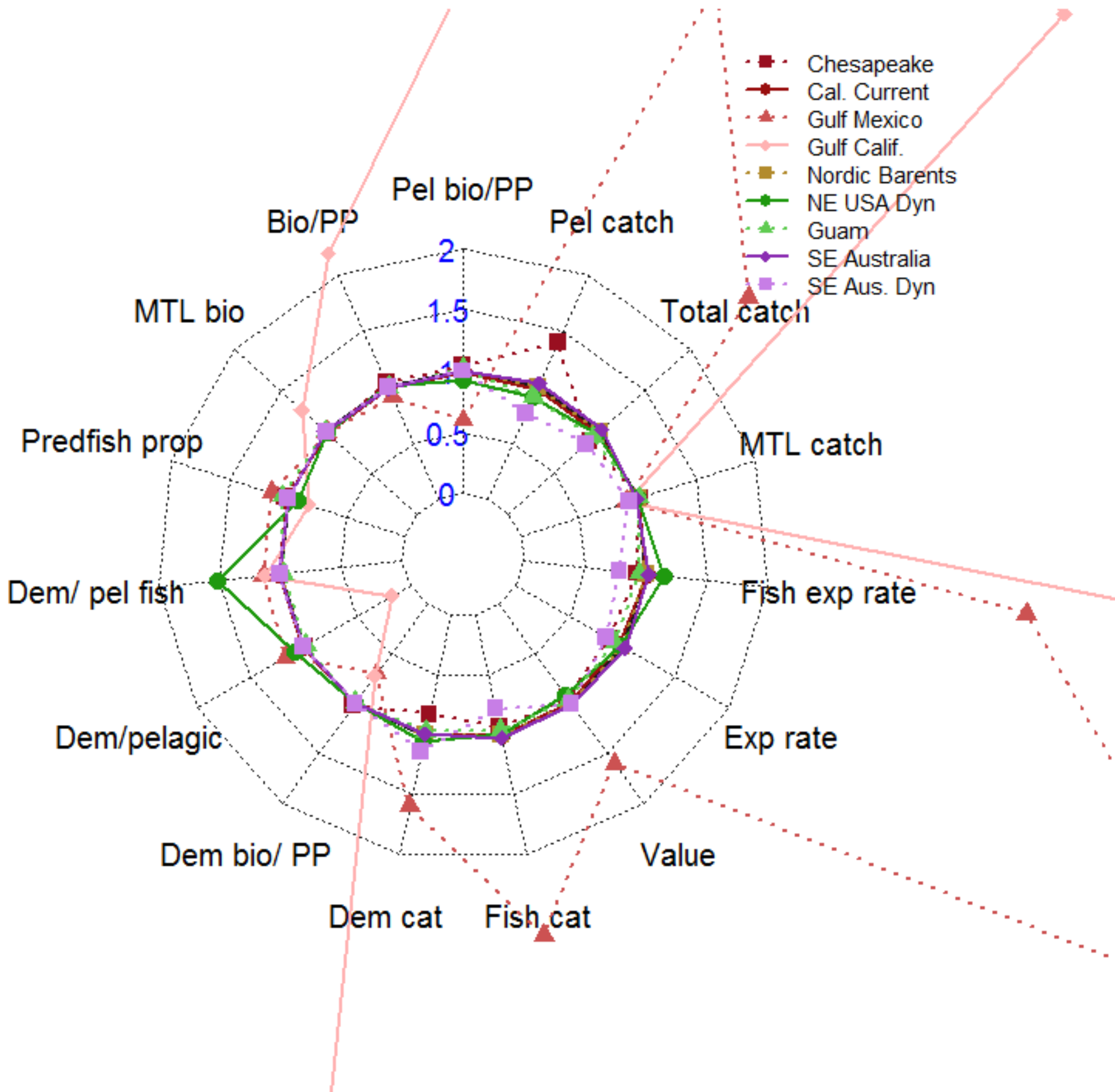


***Fig S17. Ecological and Fishery metrics for scenarios of spatial management closing 10% of continental shelf (<250m depth) to fishing. Metrics are generally ordered by: Ecological metrics (left), fishery metrics (right), pelagic (top), demersal (bottom).***

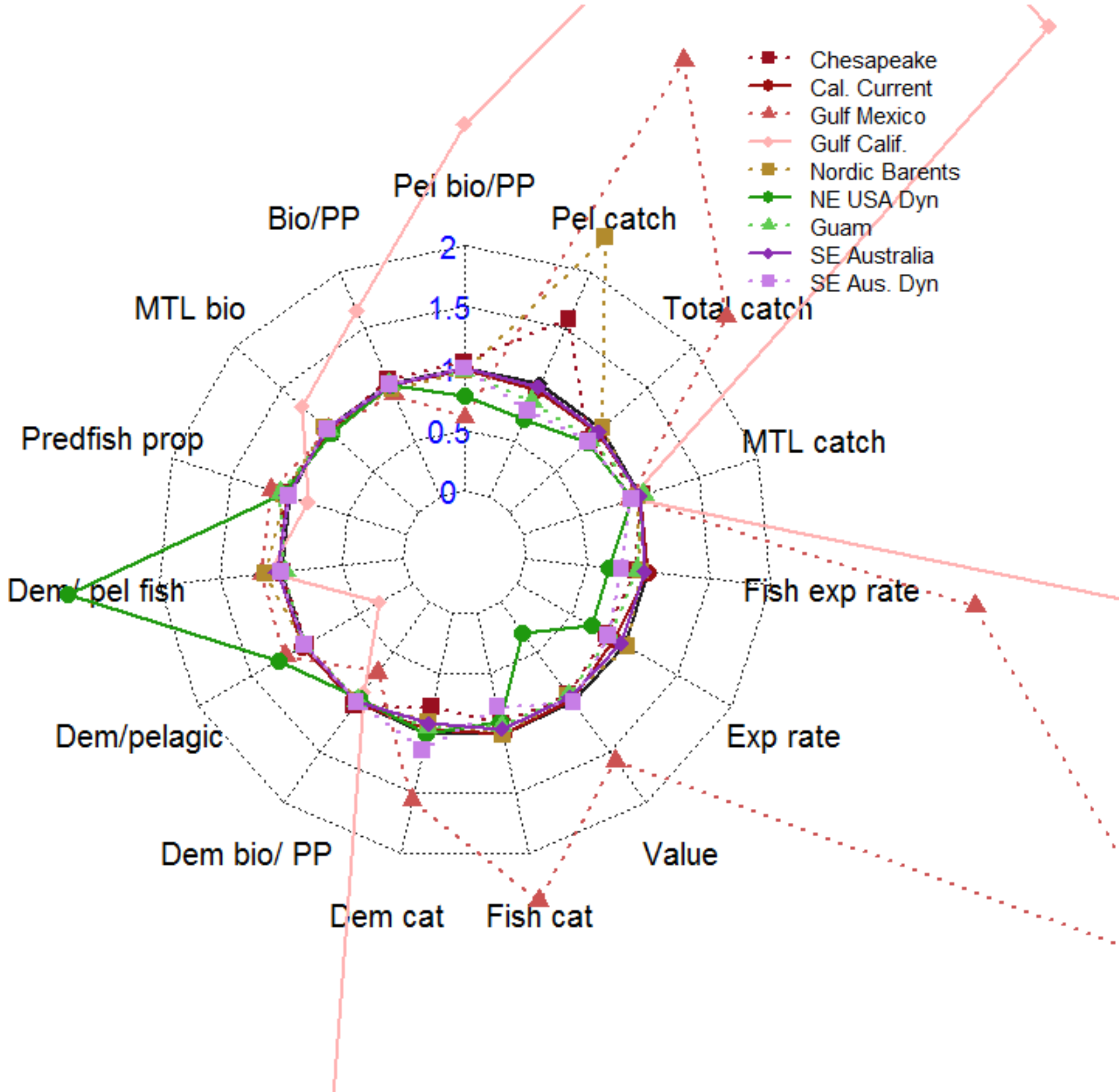


***Fig S18. Ecological and Fishery metrics for scenarios of spatial management closing 25% of continental shelf (<250m depth) to fishing. Metrics are generally ordered by: Ecological metrics (left), fishery metrics (right), pelagic (top), demersal (bottom).***

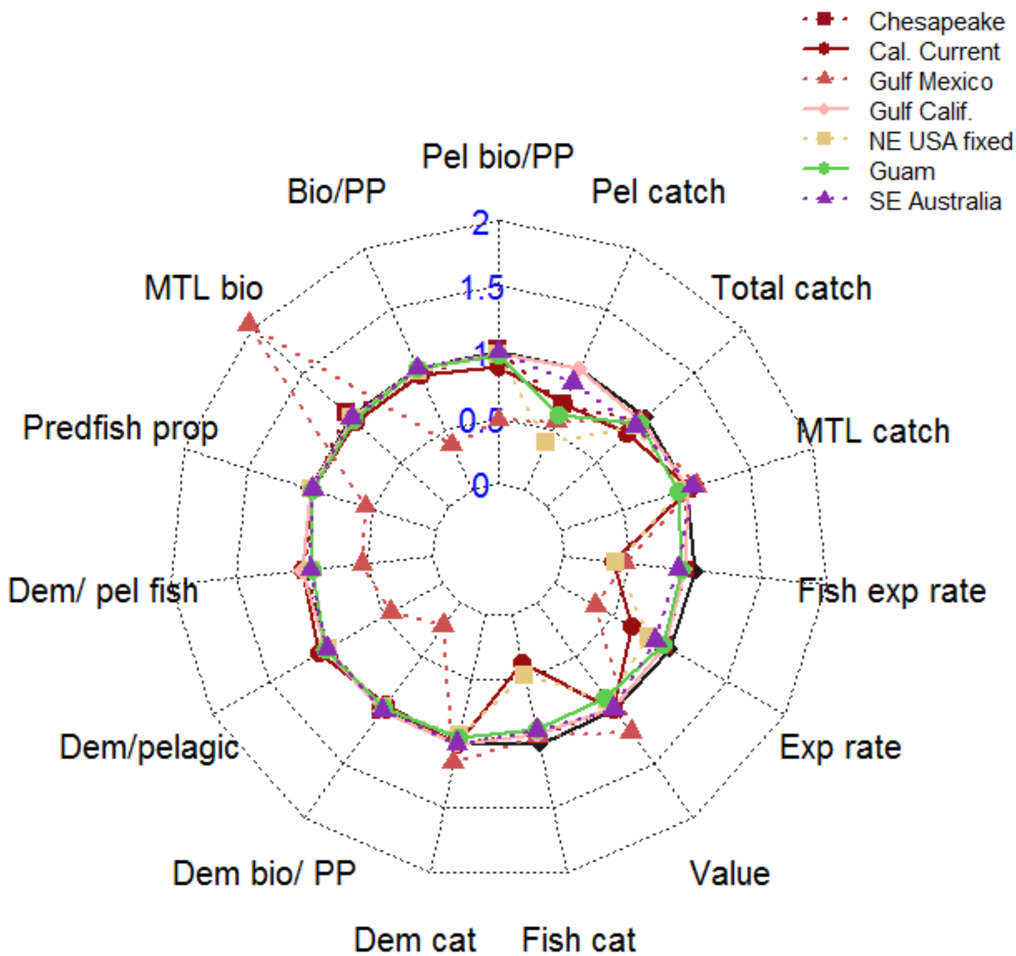


***Fig S19. Ecological and Fishery metrics for scenarios with no fishing on small pelagic fish. Metrics are generally ordered by: Ecological metrics (left), fishery metrics (right), pelagic (top), demersal (bottom).***

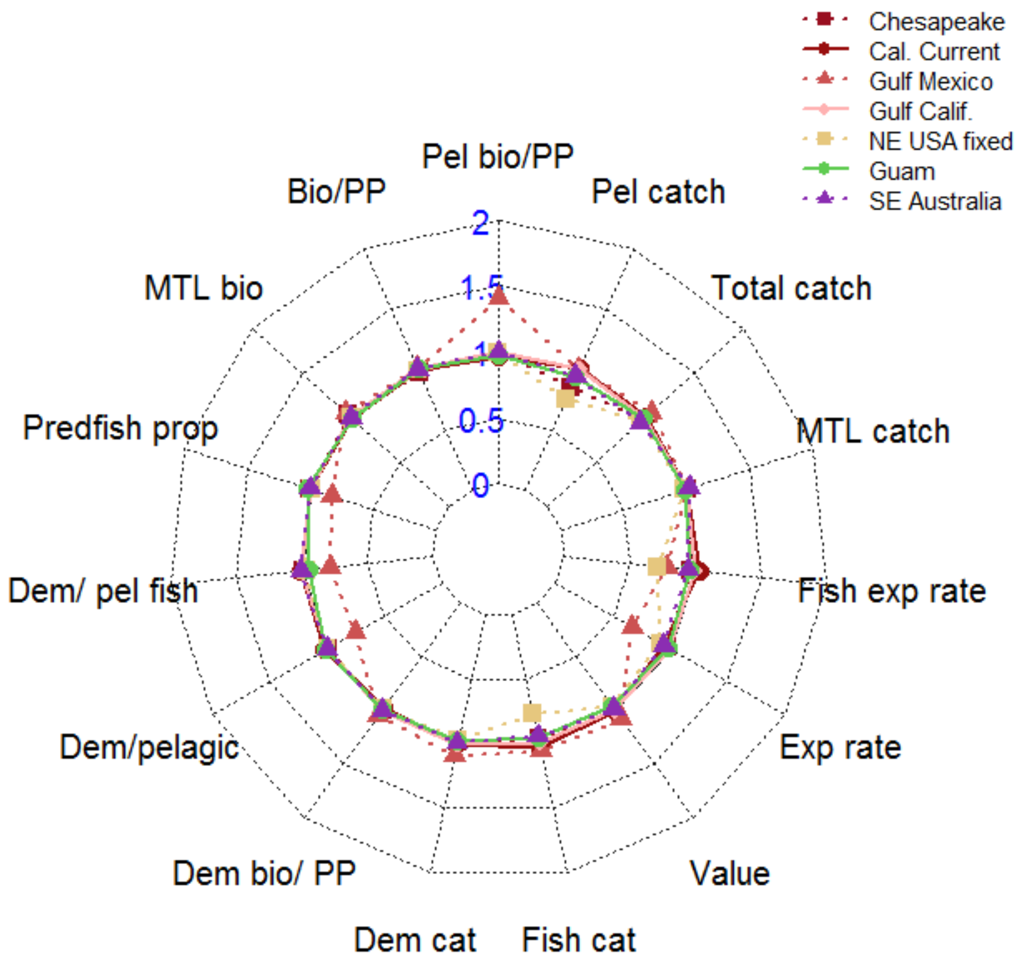


***Fig S20. Ecological and Fishery metrics for scenarios with 0.5x fishing on small pelagic fish. Metrics are generally ordered by: Ecological metrics (left), fishery metrics (right), pelagic (top), demersal (bottom).***

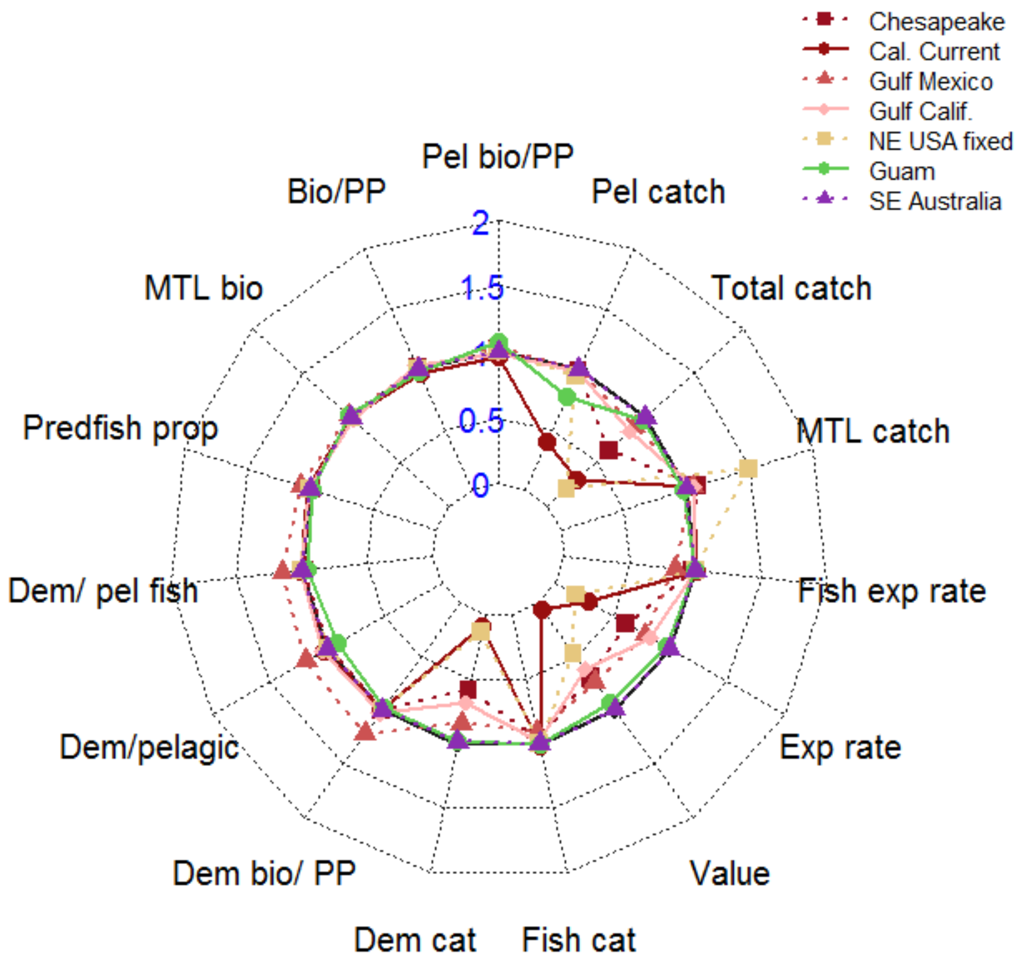


***Fig S21. Ecological and Fishery metrics for scenarios with 0x fishing on invertebrates. Metrics are generally ordered by: Ecological metrics (left), fishery metrics (right), pelagic (top), demersal (bottom).***

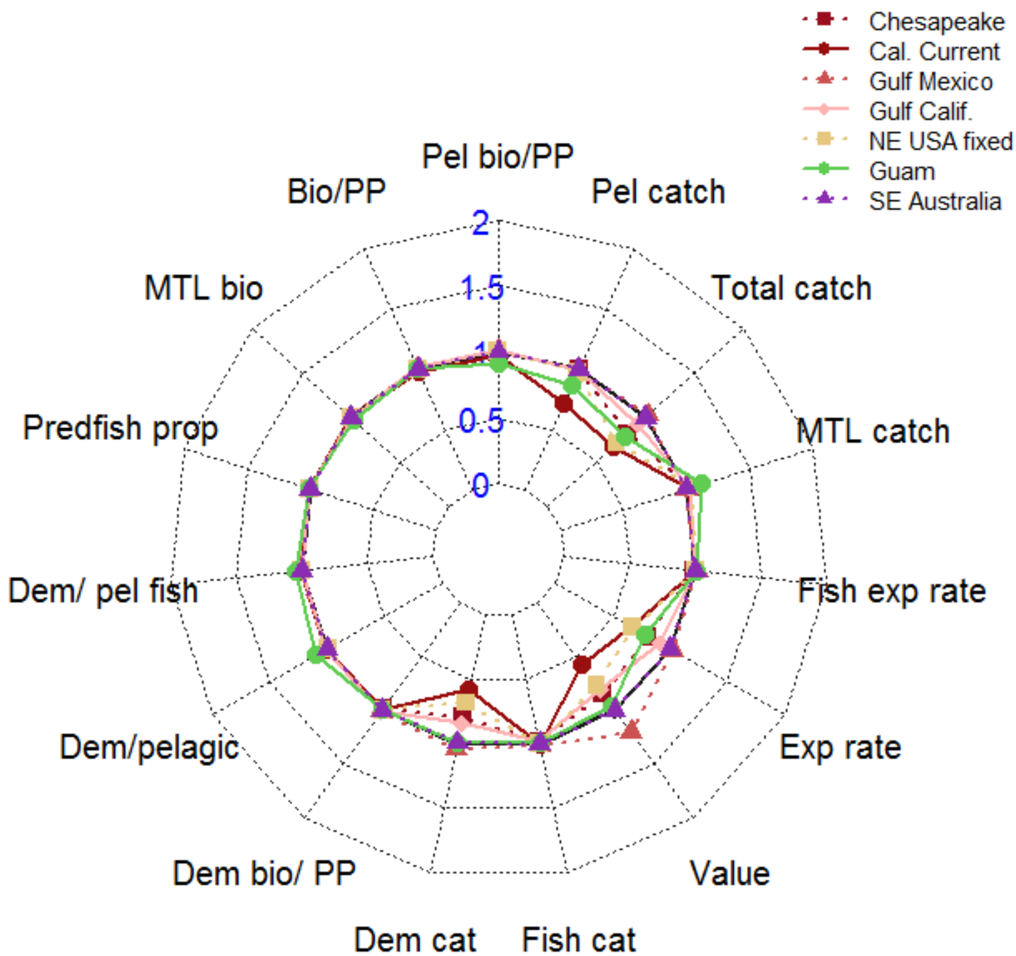


***Fig S22. Ecological and Fishery metrics for scenarios with 0.5x fishing on invertebrates. Metrics are generally ordered by: Ecological metrics (left), fishery metrics (right), pelagic (top), demersal (bottom).***

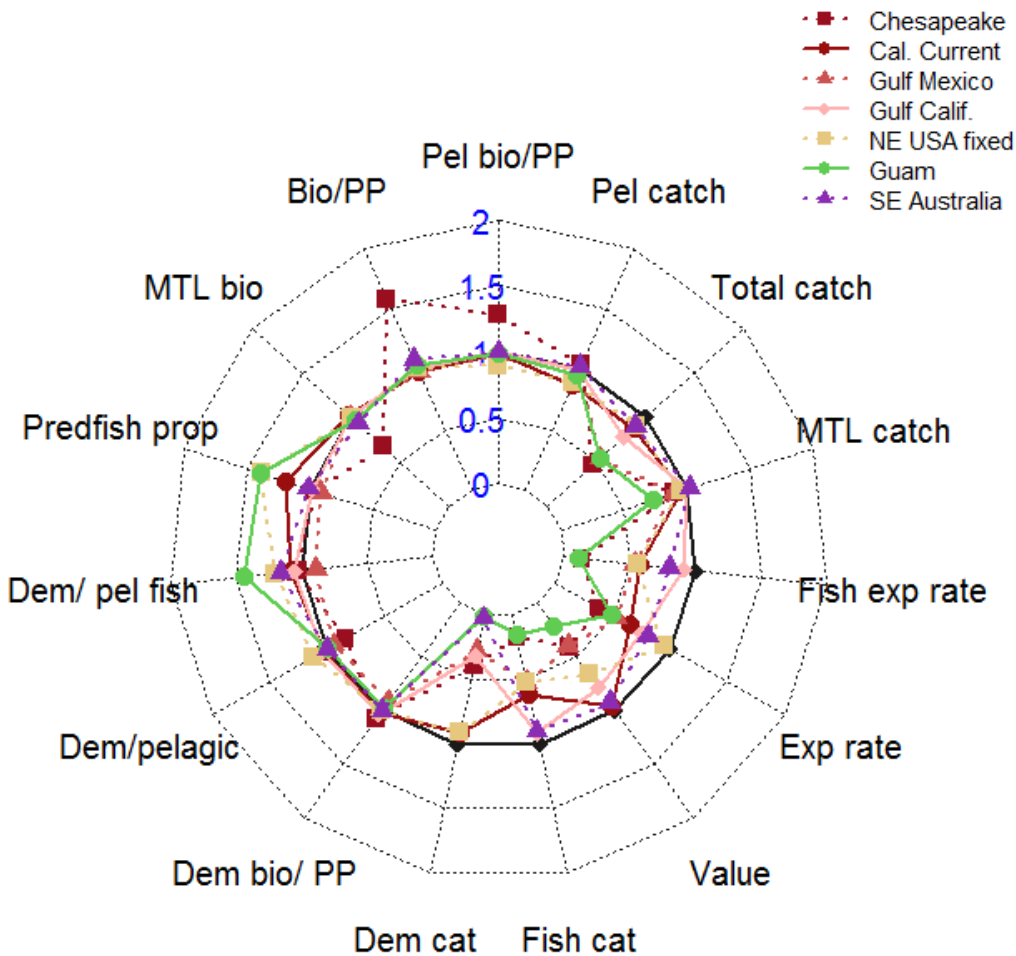


***Fig S23. Ecological and Fishery metrics for scenarios with 0x fishing on demersal fish. Metrics are generally ordered by: Ecological metrics (left), fishery metrics (right), pelagic (top), demersal (bottom).***

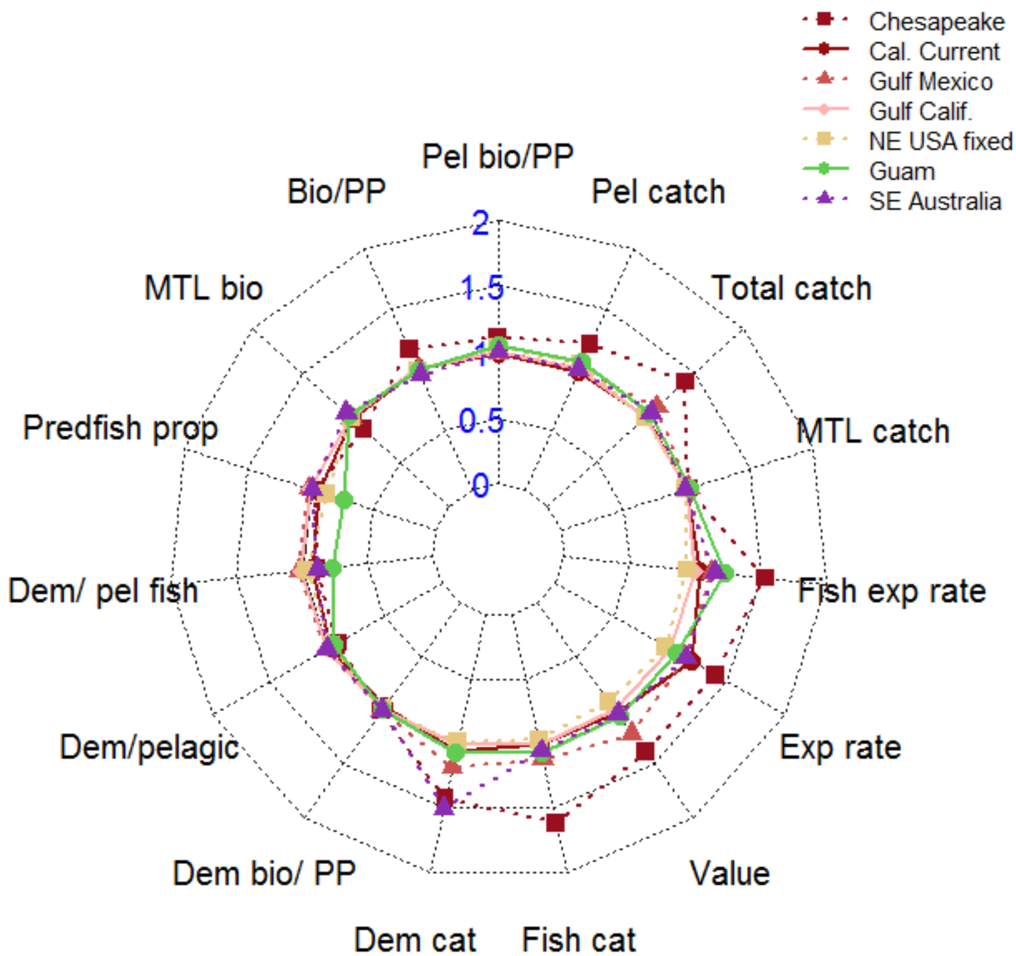


***Fig S24. Ecological and Fishery metrics for scenarios with 2x fishing on demersal fish. Metrics are generally ordered by: Ecological metrics (left), fishery metrics (right), pelagic (top), demersal (bottom).***

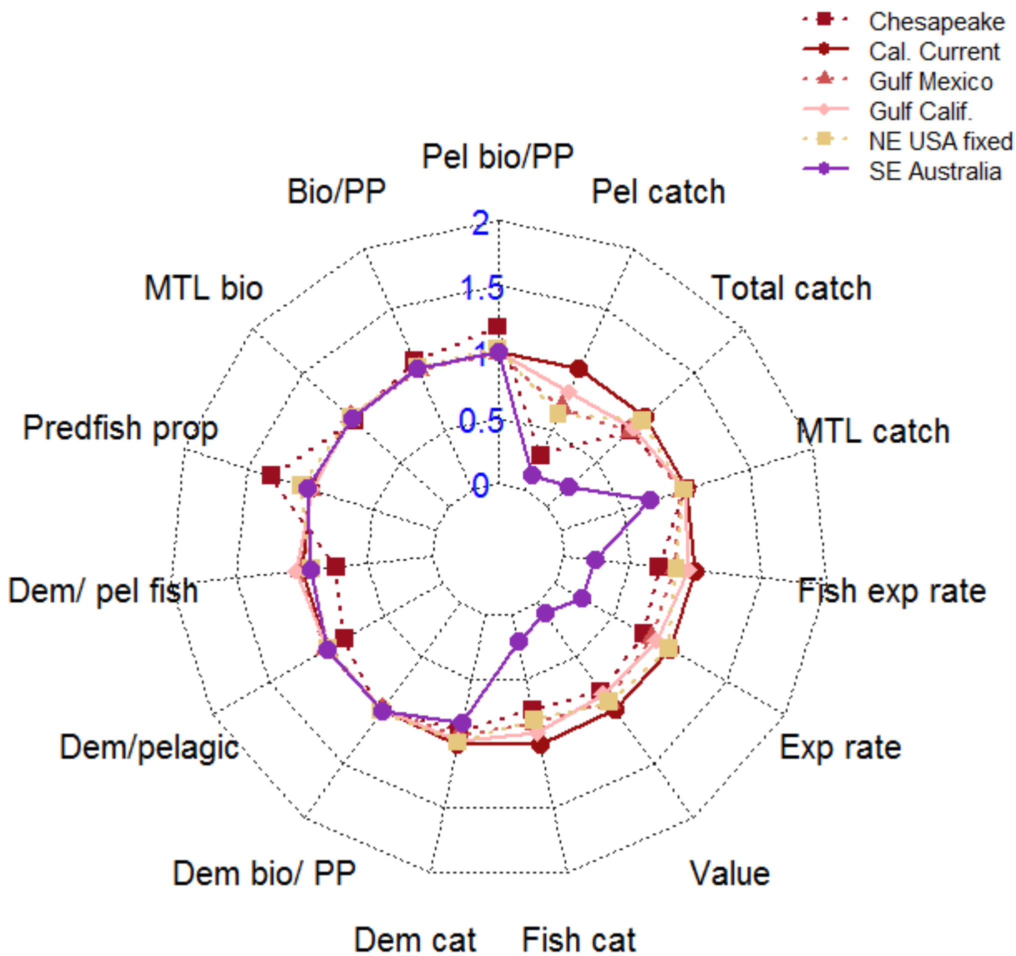


***Fig S25. Ecological and Fishery metrics for scenarios with 0x fishing on large pelagic fish. Metrics are generally ordered by: Ecological metrics (left), fishery metrics (right), pelagic (top), demersal (bottom).***

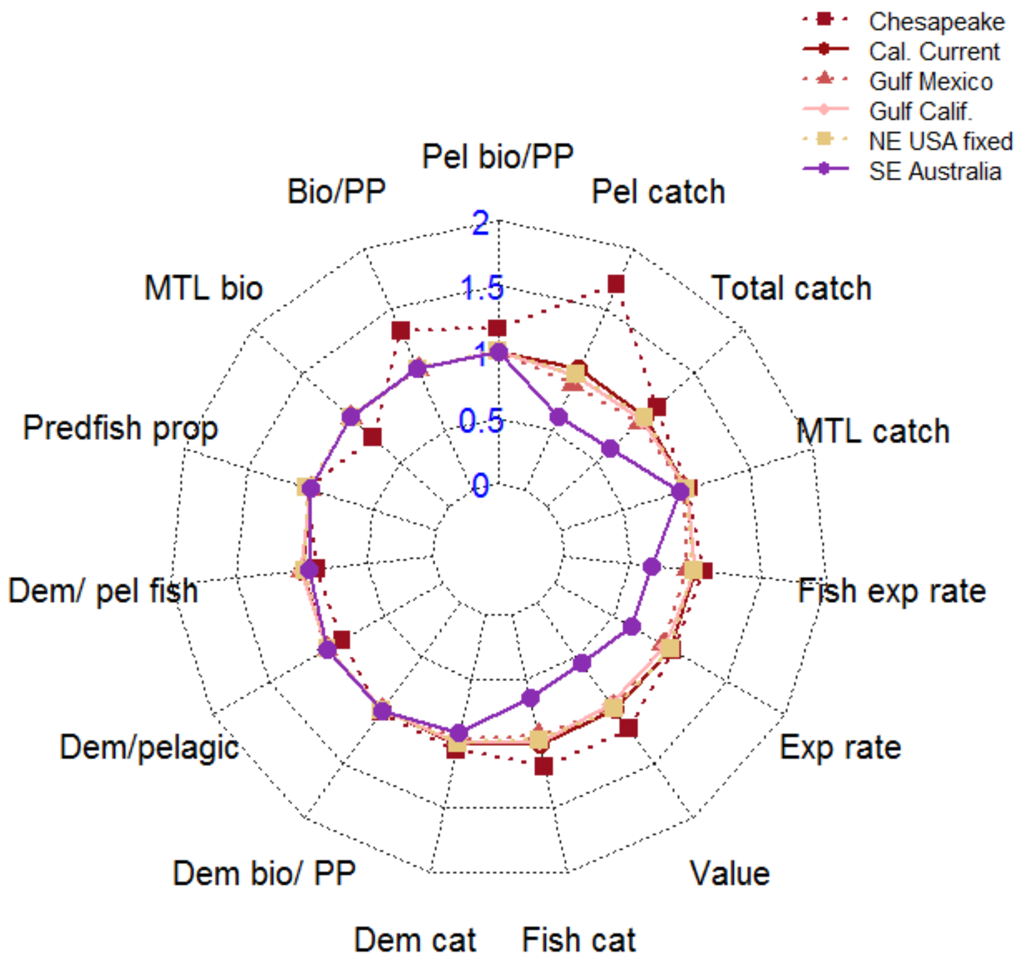


***Fig S26. Ecological and Fishery metrics for scenarios with 0.5x fishing on large pelagic fish. Metrics are generally ordered by: Ecological metrics (left), fishery metrics (right), pelagic (top), demersal (bottom).***

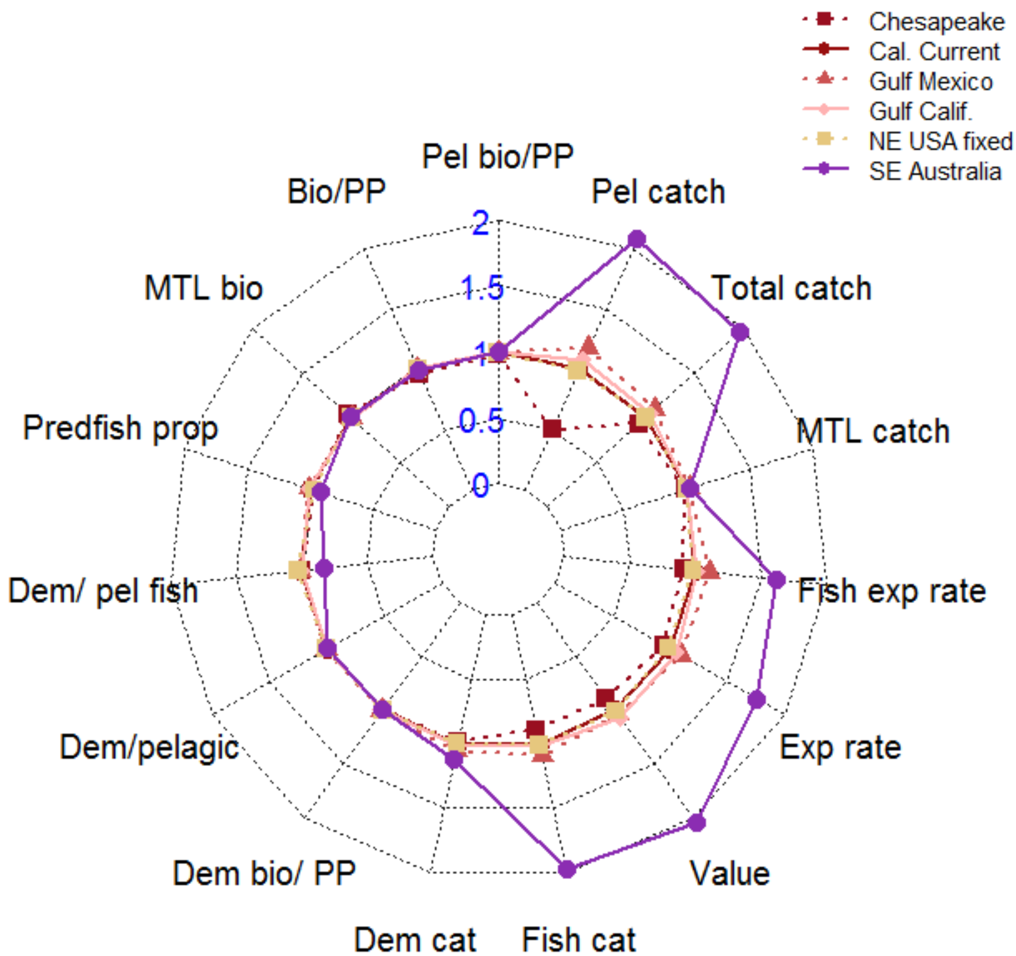


***Fig S27. Ecological and Fishery metrics for scenarios with 2x fishing on large pelagic fish. Metrics are generally ordered by: Ecological metrics (left), fishery metrics (right), pelagic (top), demersal (bottom).***

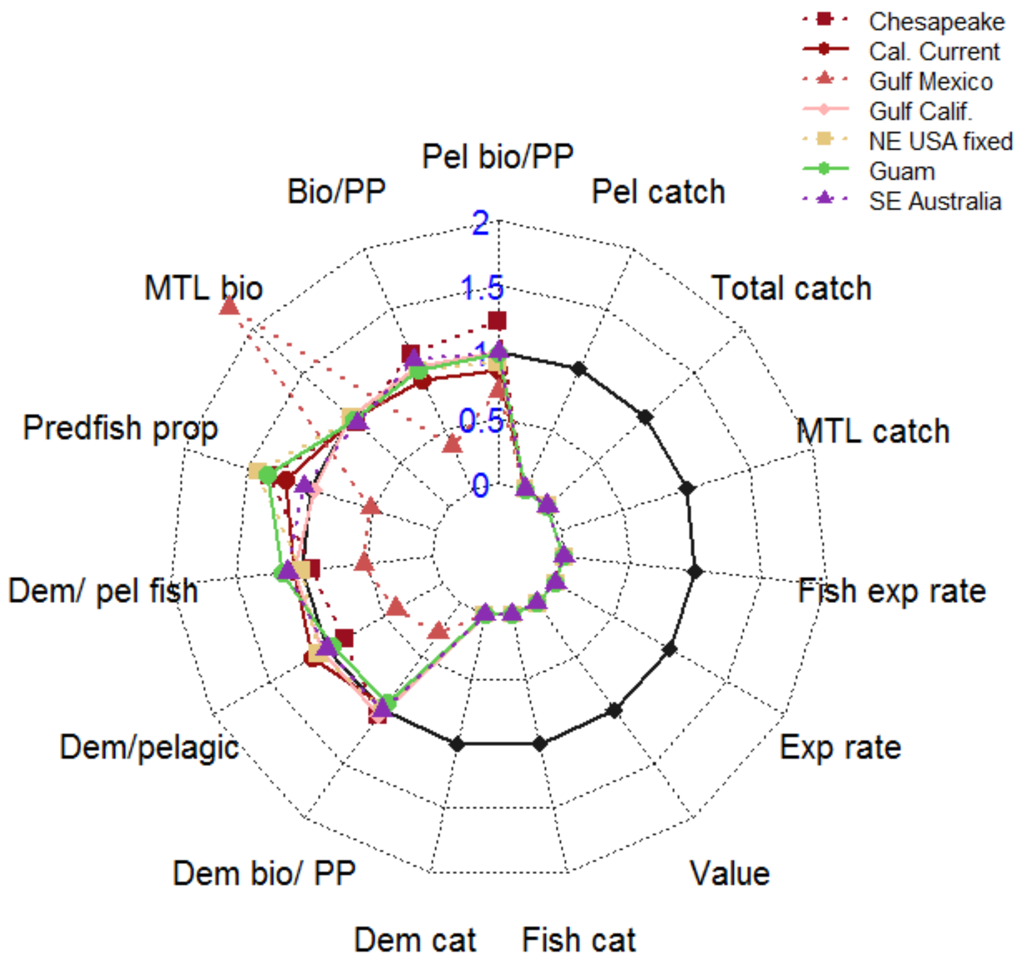


***Fig S28. Ecological and Fishery metrics for scenarios with no fishing on any group. Metrics are generally ordered by: Ecological metrics (left), fishery metrics (right), pelagic (top), demersal (bottom).***

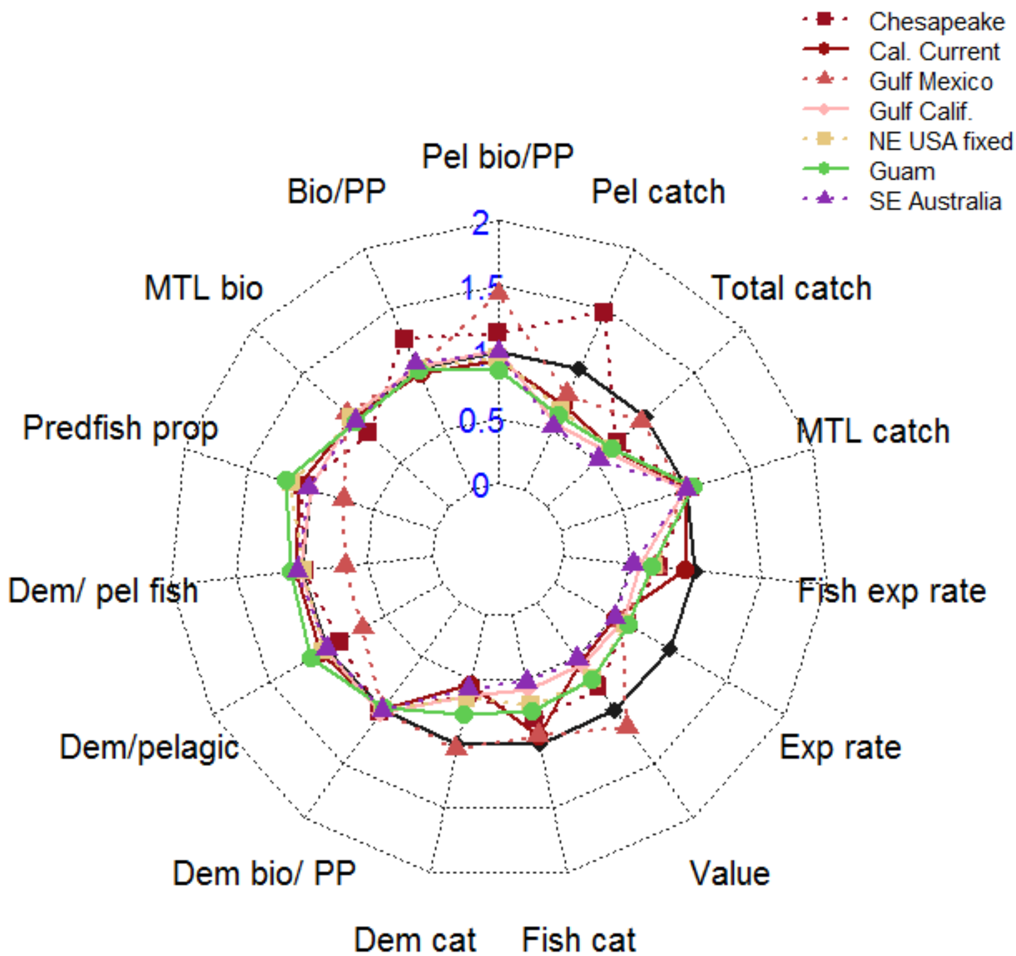


***Fig S29. Ecological and Fishery metrics for scenarios with 0.5x fishing on all groups. Metrics are generally ordered by: Ecological metrics (left), fishery metrics (right), pelagic (top), demersal (bottom).***

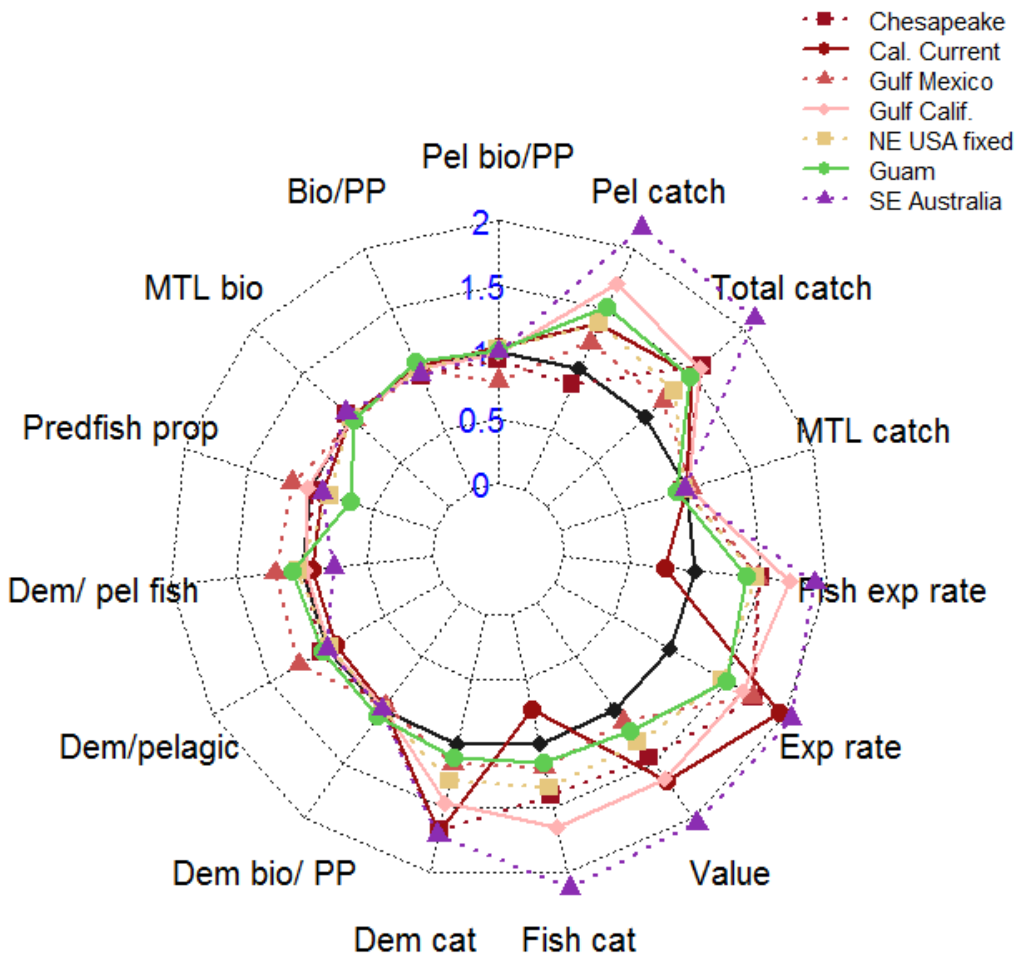


***Fig S30. Ecological and Fishery metrics for scenarios with 2x fishing on all groups. Metrics are generally ordered by: Ecological metrics (left), fishery metrics (right), pelagic (top), demersal (bottom).***

# Time-series plots of guild level biomass responses

To illustrate the dynamics of the models under these common scenarios, here we present representative time series plots of guild-level biomass responses per model (**Figures S31-S37**). Biomass response was calculated as in Figures 2b-6b (black circles from those plots) except that we recalculate this for each year of the time series, rather than reporting a single value averaged over years 45-50 of the simulation. We omit the first year of the output, for which the scenario matches the base case. We focus on dynamics of biomass response rather than the dynamics of the driver (e.g. ocean acidification mortality, or doubled fishing mortality), because in all scenarios other than the Base case, drivers were applied in year 1 and held constant through the simulation.

The time-dynamics results largely reflect three characteristics of the scenarios and responses:

1) Ocean acidification is intentionally implemented as a very strong mortality rate, primarily on calcifying organism, which is applied in year 1 and held constant through the simulations. Thus there is typically a strong immediate decline or extinction of these organisms (**Figure S31**).
2) Fishing rates are varied in a less extreme way in the MPA scenarios and the other fishing scenarios (even doubling fishing mortality rates does not usually drive species to rapid extinction or decline). Therefore in most cases the responses of fished species are more gradual, reaching somewhat stable values (in most cases) by approximately year 10-30 (Figures **S33, S34, S36, S37**).
   Note that like ocean acidification, fishing scenarios (fishing mortality or MPAs) were applied in year 1 and held constant through the simulation.
3) Indirect effects via food web connections are in almost all cases more gradual, also reaching somewhat stable values (in most cases) by approximately year 10-30 **(Figure S32, S35).**

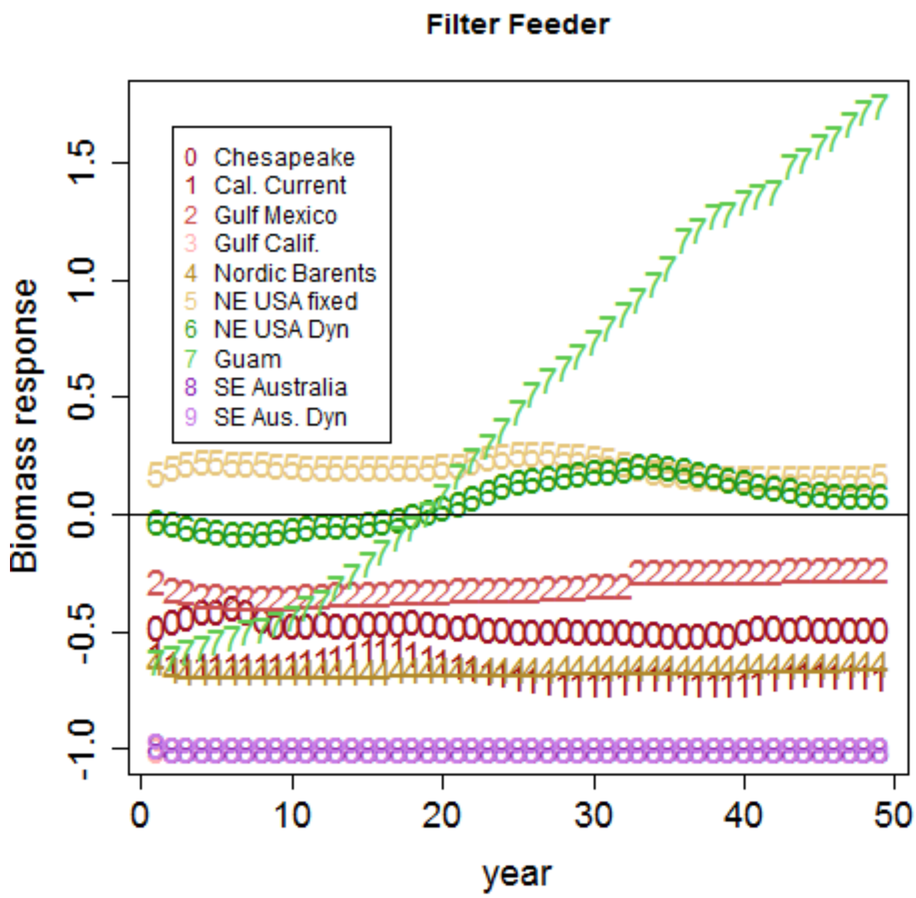


***Figure S31. Filter feeder guild response to strong ocean acidification (1% mortality rate day$^{-1}$ added for selected groups). This is a direct response to added mortality for this guild***

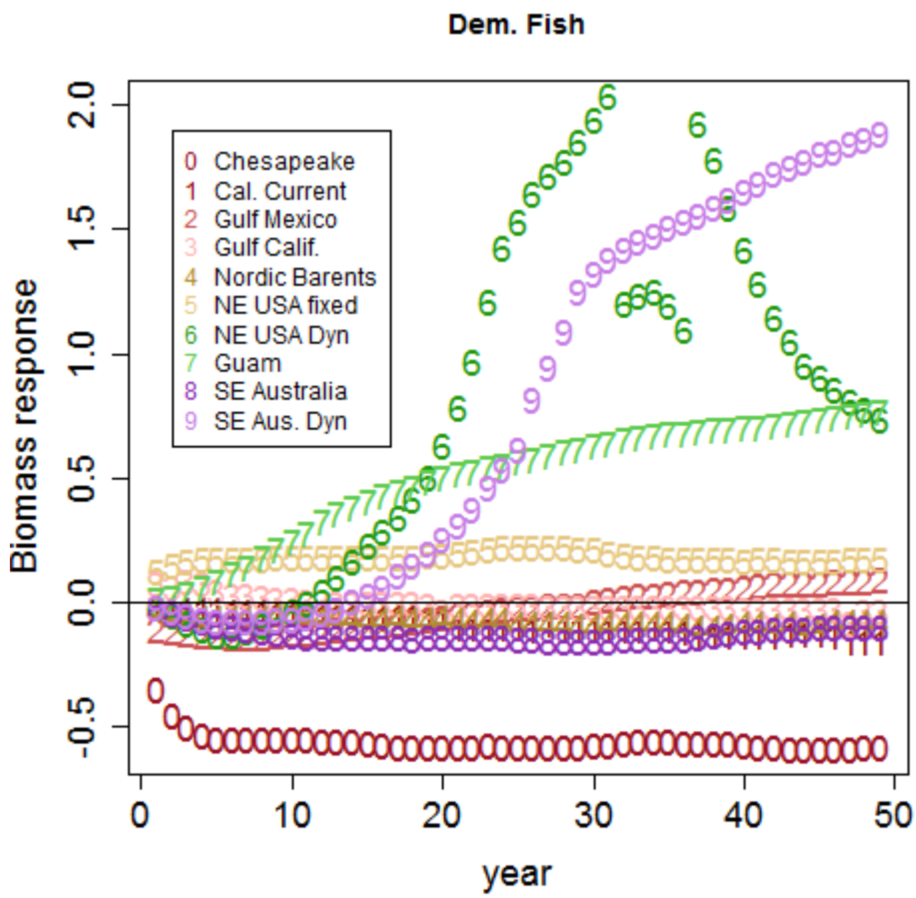


***Figure S32. Demersal fish guild response to strong ocean acidification (1% mortality rate day$^{-1}$ added for selected groups). This is an indirect response via food web connections.***

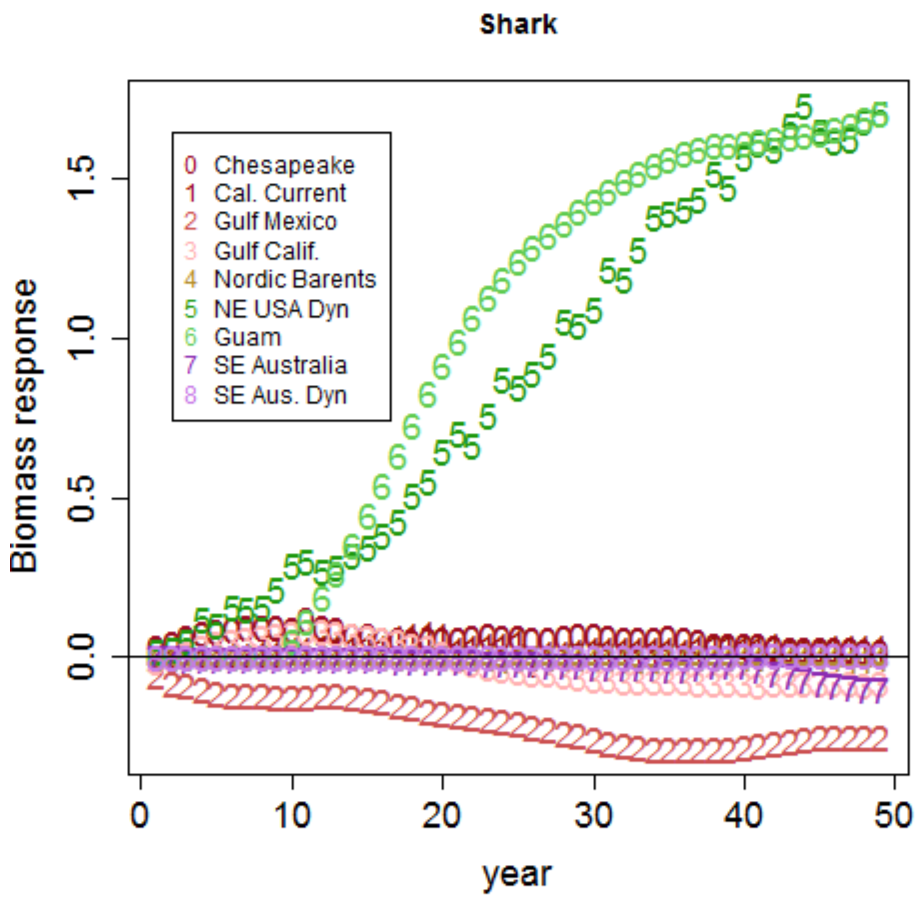


***Figure S33. Shark guild response to spatial management closing 50% of continental shelf (<250 m depth) to fishing. This is primarily a direct response to fishing.***

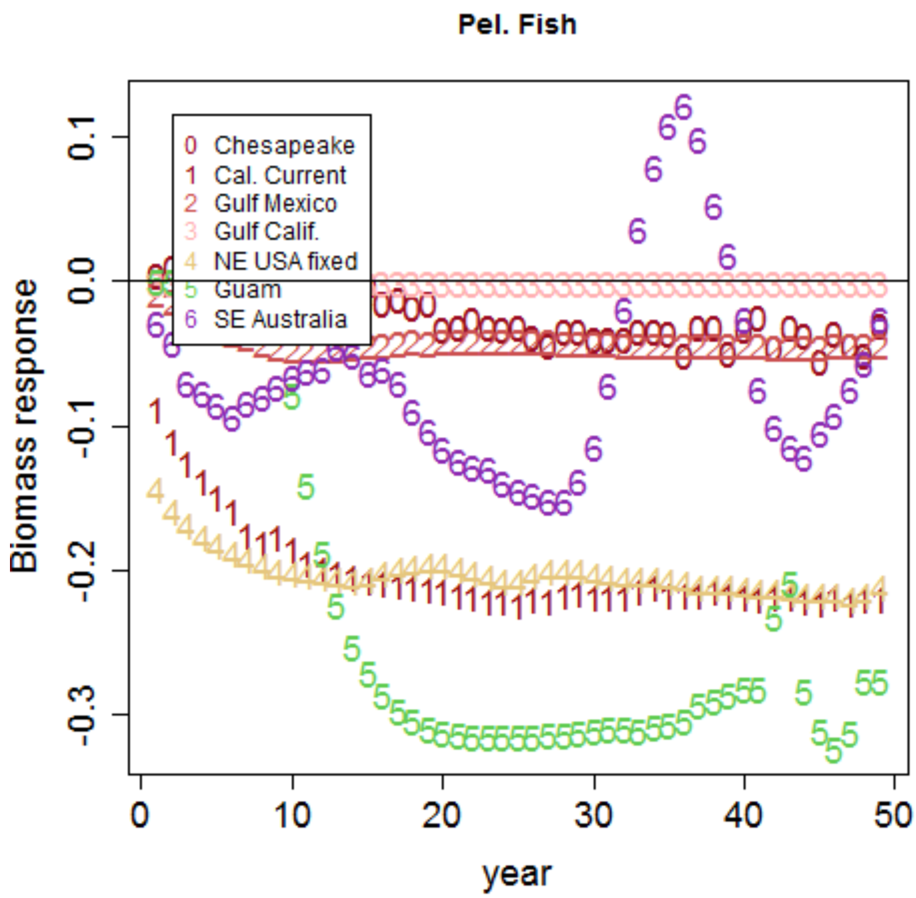


**Figure S34. Pelagic fish response to 2x fishing mortality on small pelagic fish. This is primarily a direct response to fishing.**

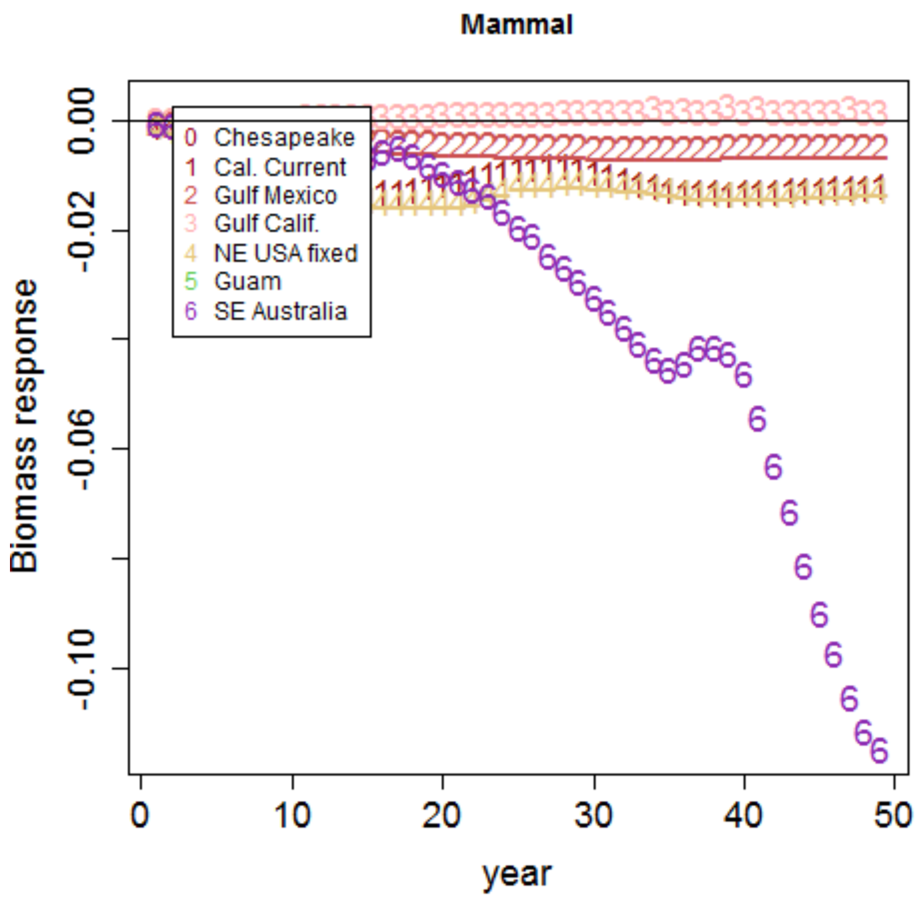


**Figure S35. Mammal guild response to 2x fishing mortality on small pelagic fish biomass (*Note range of y axis*). This is an indirect response via food web connections**

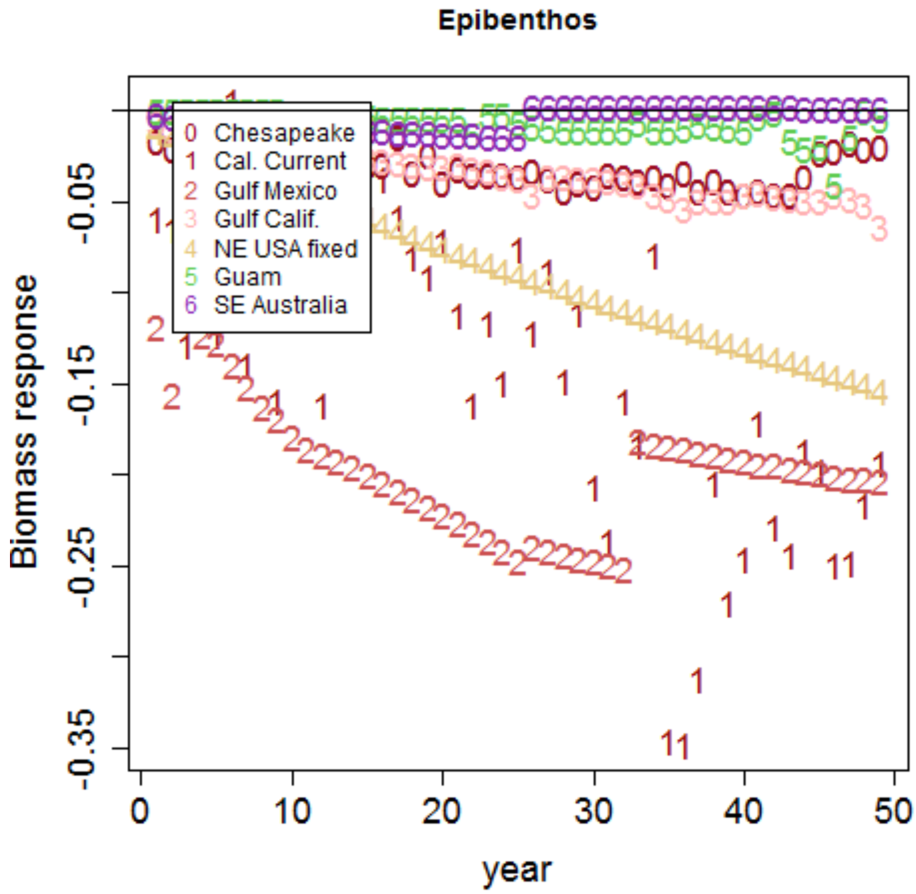


**Figure S36. Epibenthos (invertebrate) response to 2x fishing mortality on invertebrates. This is primarily a direct response to fishing.**

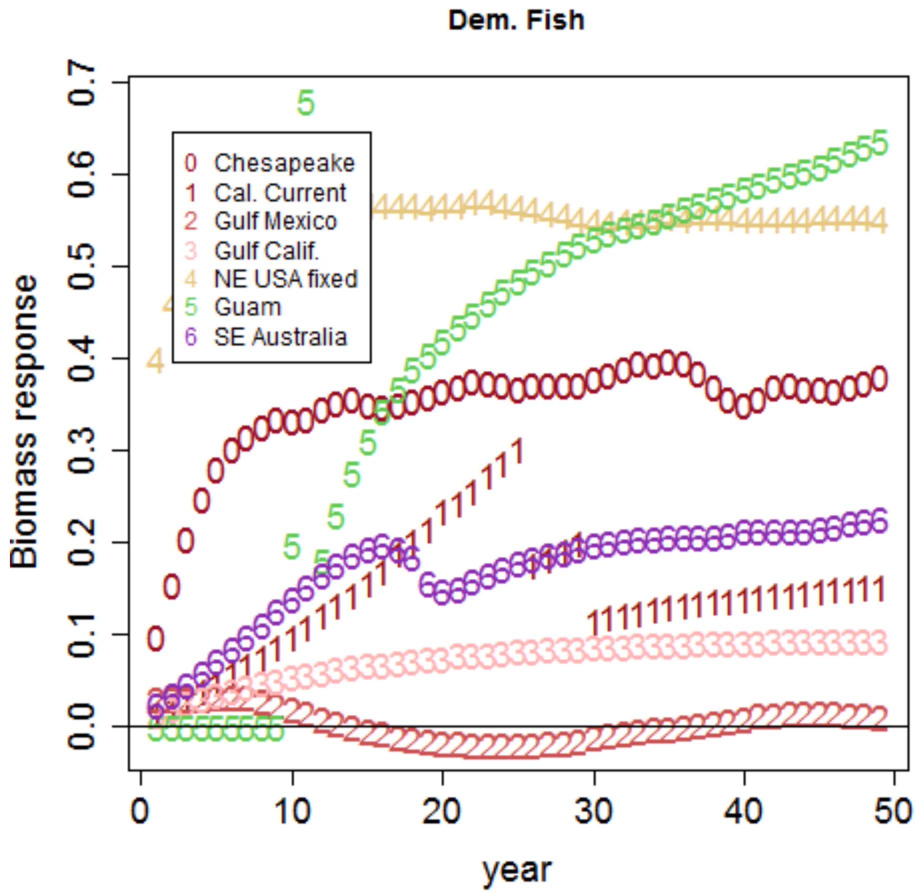


**Figure S37. Demersal fish guild response to 0.5x fishing mortality on demersal fish. This is primarily a direct response to fishing.**