Supplemental Table 1. Definitions of environmental variables within models.

|  |  |
| --- | --- |
| Variable | Definition |
| ENSO | The El Niño-Southern Oscillation index describes the recurring climate pattern across the tropical Pacific. The cool phases are known as La Niña, and the warm phases El Niño. |
| NPGO | The North Pacific Gyre Oscillation is the second leading mode of variability in the North Pacific and is related to biological and chemical properties in the Gulf of Alaska and California Current System. |
| NPI | The North Pacific Index represents area-weighted sea level pressure |
| PDO | The Pacific Decadal Oscillation is defined as the leading mode of North Pacific monthly sea surface temperature anomaly. |
| Transport | Alongshore transport of currents, wave energy and sediments. |
| Water Temp | Sea surface temperature. |
| Winds | Characteristics related to wind stress (e.g., influencing waves). |

Supplemental Table 2. Definitions of prey variables within models.

|  |  |
| --- | --- |
| Variable | Definition |
| Benthic amphipods | Benthic members of Order Amphipoda. |
| Capelin | *Mallotus villosus.* |
| Copepods | Subclass Copepoda. |
| Crabs | Tanner crab (*Chionoecetes bairdi*), King Crab (Lithodidae). |
| Euphausiids | Order Euphausiacea. |
| Hermit crabs | Family Paguridae. |
| Phytoplankton | Kindgom Chromista. |
| Shrimp | Family Pandalidae. |

Supplemental Table 3. Definitions of focal species variables within models.

|  |  |
| --- | --- |
| Variable | Definition |
| Arrowtooth | *Atherestes stomias*, age ≥ 2. |
| Arrowtooth juveniles | Individuals <20cm (age 0 to 1). |
| Arrowtooth larvae | Age-0 ichthyoplankton. |
| Halibut | *Hippoglossus stenolepis.* |
| Halibut juveniles | Individuals <20cm (age 0 to 1). |
| Halibut larvae | Age-0 ichthyoplankton. |
| Pollock | *Gadus chalcogrammus*, age 2 to 10+. |
| Pollock juveniles | Individuals <20cm (age 0 to 1). |

Supplemental Table 4. Definitions of predator and competitor variables within models.

|  |  |
| --- | --- |
| Variable | Definition |
| P. cod | Pacific cod, *Gadus macrocephalus*, all ages. |
| Sharks and skates | Combined elasmobranch predators including salmon shark (*Lamna ditropis*), dogfish (*Squalus acanthius*), big skate (*Raja binoculata*), and longnose skate (*Raja rhina*). |

Supplemental Table 5. Definitions of communities of practice-related variables within models.

|  |  |
| --- | --- |
| Variable | Definition |
| Arrowtooth active vessels | The number of active vessels with landings of arrowtooth. |
| Arrowtooth price | Revenue per unit weight of arrowtooth in US dollars. |
| Arrowtooth total landings | Total retained weight of arrowtooth by arrowtooth active vessels. |
| Arrowtooth vessel costs | Total costs of operating arrowtooth active vessels. |
| Arrowtooth vessel profits | Arrowtooth vessel revenue minus arrowtooth vessel costs. |
| Arrowtooth vessel revenue | Total revenues derived from arrowtooth landings of arrowtooth active vessels. |
| Catch sharing plan | Implemented in January 2014 (78 FR 75844), the Catch Sharing Plan creates sector allocations based on halibut abundance and allows recreational charter vessel operators in International Pacific Halibut Commission (IPHC) areas 2C and 3A to lease limited amounts of commercial individual fishing quota (IFQ) to increase the halibut available for their charter clients in the form of guided angler fish (GAF). |
| Charter business profit | Profits accruing to charter businesses as a result of charter halibut fishing trips. |
| Crew days at sea (employment) | The total number of days worked by all crewmembers on a vessel and represents harvesting sector employment in the fishery. |
| Cultural and traditional values and continuity | Cultural values associated with subsistence halibut fishing and maintaining a subsistence way of life. |
| Groundfish trawl active vessels | The number of active vessels with trawl landings of groundfish. |
| Groundfish trawl catch | Total weight of groundfish by groundfish trawl active vessels, including Prohibited Species Catch of halibut that must be discarded at-sea. |
| Groundfish trawl price | Revenue per unit weight of groundfish in US dollars. |
| Groundfish trawl vessel costs | Total costs of operating groundfish trawl active vessels. |
| Groundfish trawl vessel profit | Groundfish trawl vessel revenue minus groundfish trawl vessel costs |
| Groundfish trawl vessel revenue | Total revenues derived from groundfish trawl landings of groundfish trawl active vessels. |
| Halibut active vessels | The number of active vessels with longline landings of halibut. |
| Halibut longline landings | Total retained weight of halibut by halibut active vessels, including Individual Fishing Quota (IFQ) and Community Development Quota (CDQ) Program halibut. |
| Halibut price | Revenue per unit weight of halibut in US dollars. |
| Halibut PSC cap | The limit on the Prohibited Species Catch of halibut allowed in the directed arrowtooth flounder, pollock, and groundfish trawl fisheries. These are typically seasonal in the Gulf of Alaska, but for conceptual purposes we are considering them annually to be consistent with other time scales in the model. |
| Halibut IFQ | Represents both the Halibut Individual Fishing Quota Program (implemented in 1995) as well as the halibut long term harvest privilege (quota share). The Halibut Individual Fishing Quota Program fundamentally changed the nature of the commercial halibut fishery and has had numerous impacts on the operation of the fishery. The existence of quota shares changed the dynamics in the communities of practice by being linked to the halibut TAC, increasing vessel costs, and providing revenue to quota share holders. |
| Halibut vessel cost | Total costs of operating halibut active vessels. |
| Halibut vessel profit | Halibut vessel revenue minus halibut vessel costs |
| Halibut vessel revenue | Total revenues derived from halibut landings of halibut active vessels. |
| Individual and community health and well being | The general state of an individual or community’s quality of life, as affected by their activities related to subsistence halibut. |
| Local food security (sharing networks) | Having access to a sufficient quantity of food and maintaining local sharing networks among relatives, friends, and neighbors to maintain strong social bonds which, partially supported through subsistence fishing for halibut. |
| Pollock active vessels | The number of active vessels with landings of pollock. |
| Pollock price | Revenue per unit weight of pollock in US dollars. |
| Pollock Total landings | Total retained weight of pollock by pollock active vessels. |
| Pollock vessel costs | Total costs of operating pollock active vessels. |
| Pollock vessel profits | Pollock vessel revenue minus pollock vessel costs |
| Pollock vessel revenue | Total revenues derived from pollock landings of pollock active vessels. |
| Recreational opportunities | Providing the opportunity for individuals to enjoy charter and private angler fishing opportunities for halibut. |
| Salmon PSC cap | The limit on the Prohibited Species Catch of chinook salmon allowed in the directed pollock fishery. |
| Sport/charter catch | Total catch of halibut in the charter and sportfishing recreational fishing sectors. |
| Subsistence catch | Total catch of halibut in the subsistence and private use halibut fishery. |
| TAC Arrowtooth | Total allowable catch of arrowtooth. |
| TAC Halibut | Total allowable catch of halibut. |
| TAC Pollock | Total allowable catch of pollock. |
| Total charter businesses | Total number of businesses operating charter halibut fishing trips. |
| Total charter trips | Total number of trips taken by the charter halibut fishing sector. |
| Total sportfishing licences | Total number of sportfishing licenses used by recreational anglers. |

Supplemental Table 6. Results of bottom-up and top-down perturbation simulations with the pollock focal species model: 0 indicates no change to variable, + indicates variable increased, - indicates variable decreased. Percent of 1000 simulations with the change are indicated in parentheses. Colors indicate certainty: Blue shading indicates increase in >70% of simulations, orange decrease in >70% of simulations, and unshaded cells did not respond to the perturbation. Ambiguous responses list the percent of simulations in each direction.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Variable** | **Group** | **Simulated perturbation** | |  |
|  |  | **PDO increase** | **Phytoplankton increase** | **PSC decrease** |
| ENSO | environmental | 0 (100%) | 0 (100%) | 0 (100%) |
| NPGO | environmental | 0 (100%) | 0 (100%) | 0 (100%) |
| NPI | environmental | 0 (100%) | 0 (100%) | 0 (100%) |
| PDO | environmental | + (100%) | 0 (100%) | 0 (100%) |
| Water Temp | environmental | + (100%) | 0 (100%) | 0 (100%) |
| Winds | environmental | 0 (100%) | 0 (100%) | 0 (100%) |
| Copepods | prey | - (100%) | + (100%) | 0 (100%) |
| Euphausiids | prey | - (100%) | + (100%) | 0 (100%) |
| Phytoplankton | prey | - (100%) | + (100%) | 0 (100%) |
| Shrimps | prey | 0 (100%) | 0 (100%) | 0 (100%) |
| Juv\_pollock | focal | -(54%) +(46%) | -(68%) +(32%) | - (100%) |
| Pollock | focal | - (79%) | -(33%) + (67%) | + (100%) |
| Arrowtooth | predator/competitor | 0 (100%) | 0 (100%) | 0 (100%) |
| Halibut | predator/competitor | 0 (100%) | 0 (100%) | 0 (100%) |
| P. cod | predator/competitor | 0 (100%) | 0 (100%) | 0 (100%) |
| Crew days at sea | community of practice | - (79%) | -(33%) + (67%) | + (100%) |
| Halibut PSC cap | community of practice | 0 (100%) | 0 (100%) | - (100%) |
| Pollock active vessels | community of practice | - (79%) | -(33%) + (67%) | + (100%) |
| Pollock price | community of practice | 0 (100%) | 0 (100%) | 0 (100%) |
| Pollock total landings | community of practice | - (79%) | -(33%) + (67%) | - (100%) |
| Pollock vessel costs | community of practice | -(58%) +(42%) | -(44%) +(56%) | -(33%) + (67%) |
| Pollock vessel profits | community of practice | -(54%) + 46%) | -(49%) +(51%) | - (90%) |
| Pollock vessel revenue | community of practice | - (79%) | -(33%) + (67%) | - (100%) |
| Salmon PSC cap | community of practice | 0 (100%) | 0 (100%) | 0 (100%) |
| TAC | community of practice | - (79%) | -(33%) + (67%) | + (100%) |

Supplemental Table 7. Results of bottom-up and top-down perturbation simulations with the arrowtooth focal species model: 0 indicates no change to variable, + indicates variable increased, - indicates variable decreased. Percent of 1000 simulations with the change are indicated in parentheses. Colors indicate certainty: Blue shading indicates increase in >70% of simulations, orange decrease in >70% of simulations, and unshaded cells did not respond to the perturbation. Ambiguous responses list the percent of simulations in each direction.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Variable** | **Group** | **Simulated perturbation** | |  |
|  |  | **PDO increase** | **Phytoplankton increase** | **PSC decrease** |
| ENSO | environmental | 0 (100%) | 0 (100%) | 0 (100%) |
| NPGO | environmental | 0 (100%) | 0 (100%) | 0 (100%) |
| NPI | environmental | 0 (100%) | 0 (100%) | 0 (100%) |
| PDO | environmental | + (100%) | 0 (100%) | 0 (100%) |
| Water Temp | environmental | + (100%) | 0 (100%) | 0 (100%) |
| Winds | environmental | 0 (100%) | 0 (100%) | 0 (100%) |
| Capelin | prey | - (100%) | + (100%) | 0 (100%) |
| Copepods | prey | - (100%) | + (100%) | 0 (100%) |
| Euphausiids | prey | - (100%) | + (100%) | 0 (100%) |
| Phytoplankton | prey | - (100%) | + (100%) | 0 (100%) |
| Pollock | prey | - (85%) | + (74%) | 0 (100%) |
| Arrowtooth | focal | - (98%) | + (96%) | + (100%) |
| Arrowtooth Juv | focal | - (100%) | + (100%) | 0 (100%) |
| Arrowtooth Larvae | focal | - (100%) | + (100%) | 0 (100%) |
| Arrowtooth active vessels | community of practice | 0 (100%) | 0 (100%) | 0 (100%) |
| Arrowtooth price | community of practice | 0 (100%) | 0 (100%) | 0 (100%) |
| Arrowtooth total landings | community of practice | 0 (100%) | 0 (100%) | - (100%) |
| Arrowtooth vessel costs | community of practice | + (98%) | - (96%) | - (100%) |
| Arrowtooth vessel profits | community of practice | - (98%) | + (96%) | -(49%) +(51%) |
| Arrowtooth vessel revenue | community of practice | 0 (100%) | 0 (100%) | - (100%) |
| Crew days at sea | community of practice | 0 (100%) | 0 (100%) | 0 (100%) |
| Halibut PSC cap | community of practice | 0 (100%) | 0 (100%) | - (100%) |
| TAC | community of practice | - (98%) | + (96%) | + (100%) |

Supplemental Table 8. Results of bottom-up and top-down perturbation simulations with the halibut focal species model: same notation as above.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Variable** | **Group** | **Simulated perturbation** | |  |
|  |  | **PDO increase** | **Phytoplankton increase** | **PSC decrease** |
| ENSO | environmental | 0 (100%) | 0 (100%) | 0 (100%) |
| NPGO | environmental | 0 (100%) | 0 (100%) | 0 (100%) |
| NPI | environmental | 0 (100%) | 0 (100%) | 0 (100%) |
| PDO | environmental | + (100%) | 0 (100%) | 0 (100%) |
| Water Temp | environmental | + (100%) | 0 (100%) | 0 (100%) |
| Winds | environmental | 0 (100%) | 0 (100%) | 0 (100%) |
| Benthic amphipods | prey | 0 (100%) | 0 (100%) | 0 (100%) |
| Copepods | prey | - (100%) | + (100%) | 0 (100%) |
| Crabs | prey | - (100%) | 0 (100%) | 0 (100%) |
| Euphausiids | prey | - (100%) | + (100%) | 0 (100%) |
| Hermit crabs | prey | 0 (100%) | 0 (100%) | 0 (100%) |
| Phytoplankton | prey | - (100%) | + (100%) | 0 (100%) |
| Shrimp | prey | 0 (100%) | 0 (100%) | 0 (100%) |
| Pollock | prey | - (84%) | -(32%) +(68%) | 0 (100%) |
| Halibut | focal | - (89%) | -(32%) +(68%) | + (100%) |
| Halibut Juv | focal | 0 (100%) | 0 (100%) | 0 (100%) |
| Halibut Larvae | focal | 0 (100%) | 0 (100%) | 0 (100%) |
| Sharks skates | predator/competitor | 0 (100%) | 0 (100%) | 0 (100%) |
| Crew days at sea | community of practice | -(53%) +(47%) | -(47%) +(53%) | -(49%) +(51%) |
| Halibut active vessels | community of practice | -(53%) +(47%) | -(47%) +(53%) | -(49%) +(51%) |
| Halibut longline landings | community of practice | - (89%) | -(32%) +(68%) | + (100%) |
| Halibut price | community of practice | -(51%) +(49%) | -(50%) +(50%) | -(49%) +(51%) |
| Halibut PSC cap | community of practice | 0 (100%) | 0 (100%) | - (100%) |
| Halibut IFQ | community of practice | - (89%) | -(32%) +(68%) | + (100%) |
| Halibut vessel cost | community of practice | -(48%) +(52%) | -(50%) +(50%) | -(53%) +(47%) |
| Halibut vessel profit | community of practice | -(62%) +(38%) | -(47%) +(53%) | -(36%) +(64%) |
| Halibut vessel revenue | community of practice | - (74%) | -(42%) +(58%) | + (78%) |
| TAC | community of practice | - (89%) | -(32%) +(68%) | + (100%) |
| Groundfish trawl vessel profit | community of practice | 0 (100%) | 0 (100%) | 0 (100%) |
| Groundfish trawl active vessels | community of practice | 0 (100%) | 0 (100%) | 0 (100%) |
| Groundfish trawl catch | community of practice | 0 (100%) | 0 (100%) | - (100%) |
| Groundfish trawl price | community of practice | 0 (100%) | 0 (100%) | 0 (100%) |
| Groundfish trawl vessel costs | community of practice | 0 (100%) | 0 (100%) | 0 (100%) |
| Groundfish trawl vessel revenue | community of practice | 0 (100%) | 0 (100%) | 0 (100%) |
| Catch sharing plan | community of practice | 0 (100%) | 0 (100%) | 0 (100%) |
| Charter business profit | community of practice | - (89%) | -(32%) +(68%) | + (100%) |
| Recreational opportunities | community of practice | - (89%) | -(32%) +(68%) | + (100%) |
| Sport charter catch | community of practice | - (89%) | -(32%) +(68%) | + (100%) |
| Total charter businesses | community of practice | - (89%) | -(32%) +(68%) | + (100%) |
| Total charter trips | community of practice | - (89%) | -(32%) +(68%) | + (100%) |
| Total sportfishing licenses | community of practice | - (89%) | -(32%) +(68%) | + (100%) |
| Cultural and traditional values and continuity | community of practice | - (89%) | -(32%) +(68%) | + (100%) |
| Individual and community health and well being | community of practice | - (89%) | -(32%) +(68%) | + (100%) |
| Local food security sharing networks | community of practice | - (89%) | -(32%) +(68%) | + (100%) |
| Subsistence catch | community of practice | - (89%) | -(32%) +(68%) | + (100%) |

Supplemental Table 9. Results of bottom-up and top-down perturbation simulations with the merged model: same notation as above.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Variable** | **Group** | **Simulated perturbation** | |  |
|  |  | **PDO increase** | **Phytoplankton increase** | **PSC decrease** |
| ENSO | environmental | 0 (100%) | 0 (100%) | 0 (100%) |
| NPGO | environmental | 0 (100%) | 0 (100%) | 0 (100%) |
| NPI | environmental | 0 (100%) | 0 (100%) | 0 (100%) |
| PDO | environmental | + (100%) | 0 (100%) | 0 (100%) |
| Water Temp | environmental | + (100%) | 0 (100%) | 0 (100%) |
| Winds | environmental | 0 (100%) | 0 (100%) | 0 (100%) |
| Benthic amphipods | prey | 0 (100%) | 0 (100%) | 0 (100%) |
| Capelin | prey | - (100%) | + (100%) | 0 (100%) |
| Copepods | prey | - (100%) | + (100%) | 0 (100%) |
| Crabs | prey | - (100%) | 0 (100%) | 0 (100%) |
| Euphausiids | prey | - (100%) | + (100%) | 0 (100%) |
| Hermit crabs | prey | 0 (100%) | 0 (100%) | 0 (100%) |
| Phytoplankton | prey | - (100%) | + (100%) | 0 (100%) |
| Shrimps | prey | 0 (100%) | 0 (100%) | 0 (100%) |
| Arrowtooth | focal | - (99%) | + (99%) | + (96%) |
| Arrowtooth Juv | focal | - (100%) | + (100%) | 0 (100%) |
| Arrowtooth Larvae | focal | - (100%) | + (100%) | 0 (100%) |
| Halibut | focal | + (74%) | - (89%) | + (75%) |
| Halibut Juv | focal | 0 (100%) | 0 (100%) | 0 (100%) |
| Halibut larvae | focal | 0 (100%) | 0 (100%) | 0 (100%) |
| Pollock | focal | + (91%) | - (89%) | - (74%) |
| Pollock Juv | focal | -(33%) +(67%) | - (73%) | - (81%) |
| P. cod | predator/competitor | 0 (100%) | 0 (100%) | 0 (100%) |
| Sharks and skates | predator/competitor | 0 (100%) | 0 (100%) | 0 (100%) |
| Arrowtooth active vessels | community of practice | 0 (100%) | 0 (100%) | 0 (100%) |
| Arrowtooth price | community of practice | 0 (100%) | 0 (100%) | 0 (100%) |
| Arrowtooth total landings | community of practice | 0 (100%) | 0 (100%) | - (100%) |
| Arrowtooth vessel costs | community of practice | + (91%) | - (90%) | - (80%) |
| Arrowtooth vessel profits | community of practice | - (91%) | + (90%) | -(51%) +(49%) |
| Arrowtooth vessel revenue | community of practice | 0 (100%) | 0 (100%) | - (100%) |
| Catch sharing plan | community of practice | 0 (100%) | 0 (100%) | 0 (100%) |
| Charter business profit | community of practice | + (74%) | - (89%) | + (75%) |
| Crew days at sea employment | community of practice | + (76%) | - (74%) | -(63%) +(37%) |
| Cultural traditional values continuity | community of practice | + (74%) | - (89%) | + (75%) |
| Groundfish trawl active vessels | community of practice | 0 (100%) | 0 (100%) | 0 (100%) |
| Groundfish trawl catch | community of practice | 0 (100%) | 0 (100%) | - (100%) |
| Groundfish trawl price | community of practice | 0 (100%) | 0 (100%) | 0 (100%) |
| Groundfish trawl vessel costs | community of practice | 0 (100%) | 0 (100%) | 0 (100%) |
| Groundfish trawl vessel profit | community of practice | 0 (100%) | 0 (100%) | 0 (100%) |
| Groundfish trawl vessel revenue | community of practice | 0 (100%) | 0 (100%) | 0 (100%) |
| Halibut active vessels | community of practice | -(50%) +(50%) | -(49%) +(51%) | -(46%) +(54%) |
| Halibut longline landings | community of practice | + (74%) | - (89%) | + (75%) |
| Halibut price | community of practice | -(49%) +(51%) | -(50%) +(50%) | -(49%) +(51%) |
| Halibut PSC cap | community of practice | 0 (100%) | 0 (100%) | - (100%) |
| Halibut IFQ | community of practice | + (74%) | - (89%) | + (75%) |
| Halibut vessel cost | community of practice | +(71%) | -(69%) +(31%) | -(62%) +(38%) |
| Halibut vessel profit | community of practice | -(69%) +(31%) | -(38%) +(62%) | -(35%) +(65%) |
| Halibut vessel revenue | community of practice | -(36%) +(64%) | - (73%) | -(36%) +(64%) |
| Individual community health well being | community of practice | + (74%) | - (89%) | + (75%) |
| Local food security | community of practice | + (74%) | - (89%) | + (75%) |
| Pollock active vessels | community of practice | + (91%) | - (89%) | - (74%) |
| Pollock price | community of practice | 0 (100%) | 0 (100%) | 0 (100%) |
| Pollock Total landings | community of practice | + (91%) | - (89%) | - (100%) |
| Pollock vessel costs | community of practice | -(37%) +(63%) | -(60%) +(40%) | -(57%) +(43%) |
| Pollock vessel profits | community of practice | -(43%) +(57%) | -(57%) +(43%) | -(67%) +(33%) |
| Pollock vessel revenue | community of practice | + (91%) | - (89%) | - (100%) |
| Recreational opportunities | community of practice | + (74%) | - (89%) | + (75%) |
| Salmon PSC cap | community of practice | 0 (100%) | 0 (100%) | 0 (100%) |
| Sport charter catch | community of practice | + (74%) | - (89%) | + (75%) |
| Subsistence catch | community of practice | + (74%) | - (89%) | + (75%) |
| TAC Arrowtooth | community of practice | - (100%) | + (99%) | + (96%) |
| TAC Halibut | community of practice | + (74%) | - (89%) | + (75%) |
| TAC Pollock | community of practice | + (91%) | - (89%) | - (74%) |
| Total charter businesses | community of practice | + (74%) | - (89%) | + (75%) |
| Total charter trips | community of practice | + (74%) | - (89%) | + (75%) |
| Total sportfishing licenses | community of practice | + (74%) | - (89%) | + (75%) |