**Table S1.** Differences in the modelling approaches of four studies of mariculture production potential1.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | **Gentry et al. (2017)** | **Froehlich et al. (2018)** | **Costello et al. (2019)** | **Present study** |
| **Parameter** | **Biological potential today** | **Biological potential under CC** | **Economic potential today** | **Economic potential under CC** |
| *Model specifications* |  |  |  |  |
| Number of species | 180 (120 finfish, 60 bivalves) | 180 (120 finfish, 60 bivalves) | 180 (120 finfish, 60 bivalves) | 200 (136 finfish, 64 bivalves) |
| Spatial resolution | 0.042 degree | 1.0 degree | 0.042 degree | 10 km |
| Temporal resolution | Today | 1 historic and 4 future periods | Today | 2021, 2051, and 2100 |
|  |  |  |  |  |
| *Production parameters* |  |  |  |  |
| Harvest size | 35 cm finfish, 4 cm bivalves | 35 cm finfish, 4 cm bivalves | 35 cm finfish, 4 cm bivalves | Species-specific |
| Time-to-harvest | Species-average | Species-average | Species-average | Species-specific |
| Length-weight params. | 1 for finfish, none for bivalves | 1 for finfish, none for bivalves | 1 for finfish, 1 for bivalves | Species-specific |
|  |  |  |  |  |
| *Constraints* |  |  |  |  |
| Human use | EEZs, minus MPAs/shipping/oil/depth | EEZs | EEZs, minus MPAs/shipping/oil/depth | EEZs |
| Environmental | SST, DO, chlorophyll (bivalves) | SST, chlorophyll/acidification (bivalves) | SST, DO, chlorophyll (bivalves) | SST, DO, SAL, CHL/acidification (bivalves) |
| Climate change | Not included | RCP 8.5 | Not included | RCPs 4.5, 6.0, and 8.5 |
| Economic feasibility | Not included | Not included | Multiple prices (supply curve) | Current price per species |
| Feed availability | Not included | Not included | Multiple scenarios | Multiple scenarios |
| % FM/FO in feed | --- | --- | Single value (Atlantic salmon) | Group-specific values |
| Feed conversion rate | --- | --- | Single value (Atlantic salmon) | Group-specific values |

1 Abbreviations: CC = climate change; EEZ = exclusive economic zone; SST = sea surface temperature; DO = dissolved oxygen; CHL = chlorophyll; SAL = salinity

**Table S2.** Representative Concentration Pathways (RCPs) evaluated in the analysis\*.

|  |  |  |
| --- | --- | --- |
| **Scenario** | **Description\*\*** | **Reference** |
| RCP 4.5 | Stabilization without overshoot pathway to 4.5 W/m2 (~650 ppm CO2 eq) at stabilization after 2100 | Clarke et al. 2007; Smith & Wigley 2006; Wise et al. 2009 |
| RCP 6.0 | Stabilization without overshoot pathway to 6.0 W/m2 (~850 ppm CO2 eq) at stabilization after 2100 | Fujino et al. 2006; Hijioka et al. 2008 |
| RCP 8.5 | Rising radiative forcing pathway leading to 8.5 W/m2 (~1370 ppm CO2 eq) by 2100 | Riahi et al. 2007 |

\* Note: RCP 2.6 is not evaluated because it is no longer likely (Raftery et al. 2017).

\*\* Based on Table 2 in van Vuuren et al. 2011.

**Table S3.** Environmental variables and lethal limits used to map the suitability of ocean cells for finfish or bivalve mariculture.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Code (native units)1** | **Variable (converted units)2** | **Finfish limits** | **Bivalves limits** | **Limit reference** |
| tos (K) | Temperature (°C) | species-specific | species-specific | AquaMaps |
| so (psu) | Salinity (psu) | species-specific | species-specific | AquaMaps |
| o2 (mol/m3) | Dissolved oxygen concentration (mol/m3) | > 0.2757 mol/m3 (> 4.41 mg/L) | > 0.1244 mol/m3 (> 1.99 mg/L) | Gentry et al. (2017) |
| chl (kg/m3) | Total chlorophyll concentration (mg/m3) | not limiting | Mean minus s.d. > 0.4 mg/m3 | Froehlich et al. (2018) |
| ----- | Aragonite saturation (Ω, ratio) | not limiting | > 1.0 | Froehlich et al. (2018) |

1 Name and units of the environmental variable output by CMIP5 earth system models including the GDFL-ESM2G used here.

2 All variables reflect values at the ocean surface.

**Table S4.** Environmental variables used to calculate aragonite saturation (Ω) using the *seacarb* R package.

|  |  |
| --- | --- |
| **Code (native units)1** | **Variable (converted units)2** |
| tos (K) | Temperature (°C) |
| so (psu) | Salinity (psu) |
| ----- | Atmospheric pressure (set to 1 atm) |
| ----- | Hydrostatic pressure (set to 0 bar) |
| po4 (mol/m3) | Total phosphate concentration (mol/kg) |
| si (mol/m3) | Total silicate concentration (mol/kg) |
| ----- | Any two of the following: |
| talk (mol/m3) | Alkalinity (mol/kg) |
| dissic (mol/m3) | Dissolved inorganic carbon concentration (mol/kg) |
| ----- | Not used: pH, CO2, HCO3, CO3, pCO2 |
| rhopoto (kg/m3) | Density (kg/m3) - used to convert mol/m3 to mol/kg |

1 Names and units of the environmental variables provided by CMIP5 earth system models, including the GDFL-ESM2G model used in this analysis.

2 All variables reflect values at the ocean surface.

**Table S5.** Finfish and bivalve farm specifications from Gentry et al. (2017).

|  |  |
| --- | --- |
| **Parameter** | **Value** |
| *Finfish farm (1 sq. km)* |  |
| *Specifications* |  |
| Number of cages | 24 |
| Cage volume (m3) | 9,000 |
| Stocking density (juvs/m3) | 20 |
| Total number stocked | 4,320,000 |
| *Derived quantities* |  |
| Median harvest length (cm) | 35 |
| Median harvest weight (g) | 548 |
| Median biomass when harvested (mt) | 2,367 |
| Median density when harvested (kg/m3) | 11.0 |
|  |  |
| *Bivalve farm (1 sq. km)* |  |
| *Specifications* |  |
| Number of longlines | 100 |
| Longline length (m) | 4,000 |
| Stocking density (juvs/foot) | 100 |
| Total number stocked | 131,200,000 |
| *Derived quantities* |  |
| Median harvest length (cm) | 4 |
| Median harvest weight (g) | 3.01 |
| Median biomass when harvested (mt) | 395 |
| Median density when harvested (kg / m) | 9.9 |

**Table S6.** Cost parameters common to both bivalve and finfish mariculture.

|  |  |  |  |
| --- | --- | --- | --- |
| **Parameter** | **Value** | **Notes** | **Source** |
| *Labor costs* |  |  |  |
| Number of workers | 8 |  | Lester et al. 2018 |
| Number of hours / yr | 2080 | 40 hrs / week \* 52 weeks = 2080 hrs (also paid for transit time) | Lester et al. 2018 |
| Worker wage | by country | global average if not available | World Bank 2019b |
|  |  |  |  |
| *Fuel costs* |  |  |  |
| Vessel trips per year | 416 | 1 vessel makes 5 trips/wk, 1 vessel makes 3 trips/wk | Lester et al. 2018 |
| Vessel speed (km/hr) | 12.9 | 8 miles per hour | Lester et al. 2018 |
| Vessel fuel efficiency (liters/hr) | 60.6 | 16 gallons per hour | Lester et al. 2018 |
| Fuel cost (USD/liter) | by country | global average if not available | World Bank 2019a |
| Trip distance (km) | based on farm location |  |  |

**Table S7.** Cost parameters for finfish mariculture from Rubino 2008.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Type** | **Description** | **Unit** | **Baseline value** | **High-end value** |
| *Equipment costs* | |  |  |  |
| capital | cage purchase | US$/m3 | 15 | 25 |
| capital | cage mooring and installation1 | US$/m3 | 3 | 3 |
| annual | cage operating and maintenance2 | US$/m3/year | 1 | 6 |
|  |  |  |  |  |
| *Vessel costs* | |  |  |  |
| annual | vessel fixed | US$/year | 100,000 | 150,000 |
|  |  |  |  |  |
| *Feed costs* |  |  |  |  |
| annual | feed management variable | US$/cohort/month | 0 | 33.32 |
| annual | active feed monitoring variable | US$/cohort/month | 0 | 33.32 |
| capital | active feed monitoring fixed | US$/farm | 0 | 10,000 |
| annual | feed3 | US$/kg | 2.00 |  |
|  |  |  |  |  |
| *Plans* |  |  |  |  |
| annual | insurance4 | US$/year | 50,000 | 300,000 |
| annual | drug and chemical control BMP plan variable | US$/month | 0 | 21.15 |
| annual | solid control BMP plan variable | US$/month | 0 | 21.15 |
| capital | solid control BMP plan fixed | US$/farm | 0 | 1615.2 |
| capital | drug and chemical control BMP plan fixed | US$/farm | 0 | 1615.2 |
|  |  |  |  |  |
| *Other costs* |  |  |  |  |
| annual | on shore cost5 | US$/year | 150,000 | 250,000 |

1 Includes feeder and other equipment

2 Includes fuel, utilities, diving, repair, etc.

3 From Thomas et al. 2019

4 Insurance covers fish and other capital

5 Includes salaries for 1 manager and 2 office staff

**Table S8.** Cost parameters for bivalve mariculture from Rubino 2008.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  |  |  | **Baseline value** | **High-end value** |
| **Type** | **Description** | **Units** | **(used vessel)** | **(new vessel)** |
| *Equipment costs* | |  |  |  |
| capital | longline equipment and installation1 | US$/longline | 10,000 |  |
| annual | expendable supplies2 | US$/longline/year | 1,700 |  |
|  |  |  |  |  |
| *Vessel costs* | |  |  |  |
| capital | vessel (+cost of upgrades to used vessels3) | US$/vessel | 95,000 | 800,000 |
| annual | vessel maintenance | US$/vessel/year | 10,000 | 30,000 |
| annual | vessel equipment maintenance | US$/vessel/year | 5,000 |  |
|  |  |  |  |  |
| *Other costs* |  |  |  |  |
| annual | on shore cost4 | US$/year | 173,000 |  |

1 Includes 2 anchors ($2,000), 2 corner buoys ($2,000), rope and chain ($2,000), flotation ($2,000), and assembly and deployment ($2,000)

2 Includes spat collectors, grow out ropes, socking material, bag, etc.

3 Includes stripper/declumper/grader and continuous socking machine

4 Includes CEO/captain salary ($100,000/year) and vessel dockage ($20,000/year), etc.

**Table S9**. Pathways to expanding the ecological limits of capture fisheries on fed mariculture and how these pathways are implemented in a base case and progressive reform scenario.

|  |  |  |
| --- | --- | --- |
| **Action** | **Base case scenario** | **Progressive reform scenario** |
| 1. Increase the amount of raw material available for reduction |  |  |
| a. Reform capture fisheries | BAU fisheries management | Climate-adaptive fisheries management |
| b. Process more by-products for reduction | Not evaluated due to lack of data | Not evaluated due to lack of data |
| 2. Increase the proportion of fish ingredients used by mariculture |  |  |
| a. Reduce use in non-carnivorous terrestrial agriculture | XX% of forage fish to aquaculture | All forage fish go to aquaculture |
| b. Reduce use in non-carnivorous fish aquaculture | XX% of aquaculture feed to mariculture | XX% goes to mariculture |
| 3. Reduce the amount of fish ingredients in feed | Current FM/FO compositions | Projected FIFO ratios |
| 4. Reduce the feed conversion rate (i.e., increase feed efficiency) | Current feed conversion rates | Projected FIFO ratios |