**Table SX.** Timeline of Dungeness crab reproductive events, fishery season, scientific monitoring, and whale presence (simulation time steps begin on October 1st, the dashed line).

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Process** | **January** | | **February** | | **March** | | **April** | | **May** | | **June** | | **July** | | **August** | | **September** |  | **October** | | **November** | | **December** | |
| Dungeness crab |  |  |  |  | 1. Mating | | | | | | | |  |  |  |  | 2. Brooding | |  |  |  |  | 3. Hatching | |
| reproductive timing\* | 3. Hatching | | | |  |  | 4. Settlement | | | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Commercial fishing (Northern) |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Commercial fishing (Central/Southern) |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Grey whales (not evaluated) |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Humpback whales |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Scientific monitoring |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | Meat quality | | |  |  |  |
| Current RAMP assessment schedule |  |  | 2. Mid-season | |  |  | 3. Late season | | | |  |  | 4. Post-season | |  |  |  |  | 1. Preseason | | | |  |  |

\* Based on Table 3.1 from Rasmuson (2013).

**Table 1.** Evaluated management strategy scenarios.

|  |  |  |
| --- | --- | --- |
| **Scenario name** | | **Scenario description** |
| *Domoic acid (DA) risk management only* | | |
| 1 | DA-Curr | Current management |
| 2 | DA-Alt1 | Expanded pre-season sampling |
| 3 | DA-Alt2 | Expanded pre-season sampling + routine mid-season sampling |
| 4 | DA-Alt3 | Season remains open with evisceration order (+ expanded pre-season sampling + routine mid-season sampling) |
| *Whale entanglement (WE) risk management only* | | |
| 5 | WE-Orig | Original RAMP guidelines |
| 6 | WE-Settle1 | Revised RAMP guidelines, as specified in CDB vs. Bonham settlement |
| 7 | We-Settle2 | Revised RAMP guidelines, as specified in the settlement, minus the April 1st closure for Districts 10, 17, and south |
| *Joint domoic acid and whale entanglement risk management* | | |
| 8 | DA-Alt2 + WE-Settle1 | Expanded domoic acid sampling and revised RAMP guidelines |
| 9 | DA-Alt2 + WE-Settle2 | Expanded domoic acid sampling and revised RAMP guidelines (w/out April 1st closure) |
| 10 | DA-Alt3 + WE-Settle1 | Expanded domoic acid sampling with evisceration order and revised RAMP guidelines |
| 11 | DA-Alt3 + WE-Settle2 | Expanded domoic acid sampling with evisceration order and revised RAMP guidelines (w/out Apr 1st closure) |

**Table 2.** Current and alternative strategies for managing the public health risk presented by domoic acid contamination in the California Dungeness crab fishery and details on their implementation in the management strategy evaluation model.

*Current management strategies*

**1. Routine pre-season monitoring**

In late October or early November of each year, six crabs from twelve locations (6 areas, 2 locations each) are collected and measured for domoic acid concentration in their viscera. If ≥3 of the sampled crabs show domoic acid concentrations above the 30 ppm action threshold, the district is closed to fishing. viscera sampling is repeated every two weeks until resulting in two consecutive clean tests. The district is then re-opened to fishing. We simulated this process by drawing a random survey start date from a uniform distribution of historic start dates and sampling six crabs at each of the twelve locations on the appropriate date. Whether a sampled crab is contaminated above the action threshold was determined stochastically using the probabilities predicted by the random forests contamination model.

**2. Ad-hoc mid-season monitoring**

The following indicators of elevated HAB or domoic acid risk trigger ad-hoc mid-season monitoring:

1. Increased toxins in bivalves: This indicator is monitored using domoic acid measurements in razor clams from the CDPH Marine Biotoxin Monitoring Program. The indicator is triggered when…
2. Increased presence or abundance of HAB species: This indicator is monitored using *Pseudo-nitzschia* measurements at seven piers along the California coast from the CDPH Marine Biotoxin Monitoring Program. The indicator is triggered when…
3. Increased marine mammal strandings or bird die-offs:This indicator is not evaluated.

When any one of these indicators is triggered, crab viscera are sampled from locations in the at-risk district using the protocol described in Current Strategy #1 above. If this sampling finds domoic acid concentrations requiring management action, the district is closed and viscera sampling is repeated every two weeks until resulting in two consecutive clean tests. The district is then re-opened to fishing.

**3. Districts with locations failing viscera tests are closed until sampling yields two consecutive clean tests**

When a district is closed because pre-season or mid-season sampling reveals high domoic acid contamination, fishing is redistributed to areas outside the closed district by…

*Alternative management strategies*

**1. Expand the pre-season sampling program**

The prescriptiveness of the pre-season sampling program could be increased by increasing the number of sampling locations and the number of samples collected at each location. We evaluated a pre-season sampling program with 12 new sampling locations (24 locations instead of 12; the locations of original 12 sampling sites are maintained) located such that every district is sampled and the number of locations within a district is proportional to the catch from the district. We also doubled the number of crabs collected at each location (12 crabs instead of six) based on a power analysis.

**2. Establish a routine mid-season monitoring program**

In addition to initiating ad-hoc mid-season sampling when the risk indicators described in Current Strategy #2 are triggered, routine mid-season monitoring could increase the responsiveness of management actions. We evaluated two potential routine mid-season monitoring programs: (a) monthly sampling at the current pre-season sites and (b) monthly sampling at the expanded pre-season sites.

**3. Keep the fishery open but require the evisceration of crabs caught in at-risk areas**

An alternative to closing the fishery during periods of contamination risk is to require the evisceration (i.e., the removal of the contaminated viscera) of all crabs captured in at-risk districts. We simulated this strategy by requiring evisceration in any district that would otherwise be closed due to a failed viscera test. The evisceration order is only lifted when the trigger location produces two consecutive clean tests.

**Table 3.** Current and alternative strategies for managing the risk of humpback whale entanglement in the California Dungeness crab fishery and details on their implementation in the management strategy evaluation model.

*Current management strategies*

1. **Risk assessment interval (4 times per year)**

The RAMP risk assessment and management action determination is conducted four times per year: preseason (Oct/Nov), mid-season (Feb), late season (Apr/May), and postseason (Jul). We simulate the RAMP decisions on the time step closest to a date randomly drawn from each specified time window.

1. **Risk assessment framework (RAF)**

Management action is triggered by any of the following indicators of elevated whale entanglement risk:

*Entanglements*

1. ≥5 confirmed humpback whale entanglements in CA Dungeness crab commercial fishing gear in a season or offseason: The indicator is monitored using the simulated whale entanglements with two probabilities of observation: 100% and 30%.
2. ≥2 confirmed humpback whale entanglements in CA Dungeness crab commercial fishing gear in a month: The indicator is monitored using the simulated whale entanglements with two probabilities of observation: 100% and 30%.

*Fleet dynamics*

* 1. Season opening after Feb 1: This indicator is triggered when the season opens after February 1st due to either high domoic acid contamination or low meat quality.

*Ocean/forage conditions*

1. El Niño conditions: This indicator is monitored using the ROMS model sea surface temperature (SST) data that drives the C-HARM and whale species distribution model predictions. The indicator is triggered when SST was higher than average over the month before evaluation.
2. Low offshore krill abundance and high inshore anchovy abundance: This indicator is monitored using NOAA survey data and is triggered when the following occur simultaneously: krill abundance is below average and anchovy abundance is above average.

*Concentration of whales*

1. Moderate or high abundance of whales: This indicator is monitored using two NOAA surveys – the fall aerial marine mammal survey and the spring shipboard rockfish survey – and is triggered using the following delimiters of risk:
   1. **High risk:** ≥20 whales present in a 1-week running average
   2. **Moderate risk**: 5-20 whales present in a 1-week running average
   3. **Low risk:** <5 whales present in a 1-week running average
2. **Management measures toolbox (MMT)**

Management actions should be commensurate with the risk level and based on the best available science. The following management measures are available for low and elevated risk conditions:

*Low risk (none of these are evaluated)*

1. Set trap limits
2. Require gear recovery
3. Request fishers to follow best practices
4. Request fishers to participate in NOAA trainings

*Elevated risk*

1. Temporary area restrictions: When a RAMP assessment determines there is elevated risk of entanglement in a district, the district is closed to fishing until the next RAMP assessment.
2. Decrease concentration of gear outside closes areas (i.e., buffer zones) *(not evaluated)*
3. Require solar loggers to fish in an area *(not evaluated)*
4. Increase readiness of law enforcement, data gatherers, and first responders *(not evaluated)*

*Alternative management strategies: CBD v. Bonham settlement*

**1. Risk assessment interval (12 times per year)**

The RAMP risk assessment and management action determination is conducted four times per year: Nov 1, Dec 15, Jan 15, Feb 15, Mar 15, Apr 1, Apr 15, May 1, May 15, Jun 1, Jun 15, Jul 1. We simulate the RAMP decisions on the time step closest to the specified date.

**2. Risk assessment framework (RAF)**

Management action is triggered by any of the following indicators of elevated whale entanglement risk:

*Entanglements*

1. ≥1 confirmed ESA-listed species entanglements in CA-DC gear: The indicator is monitored using the simulated whale entanglements with two probabilities of observation: 100% and 30%.
2. ≥2 confirmed ESA-listed species entanglements in unknown gear: The indicator is monitored using the simulated whale entanglements with two probabilities of observation: 100% and 30%.

*Whale concentrations*

1. ≥20 ESA-listed whales in a NOAA survey: This indicator is monitored by simulating the annual survey tracks of the spring shipboard rockfish survey and fall aerial marine mammal survey over the whale densities predicted by the species distribution model. Observations are recorded using encounter probabilities based on Eq. X and detection probabilities from the literature.
2. ≥5 ESA-listed whales running average in 1 week: This risk factor is monitored using the same procedure as above.

Management action is triggered when two of the following indicators occur simultaneously:

*Fleet dynamics*

1. First two weeks of the season: This indicator reflects the fact that…
2. Season opening after Feb 1: This indicator is triggered when the season opens after February 1st due to either high domoic acid contamination or low meat quality.

*Ocean/forage conditions*

1. Upwelling below average (El Niño conditions or warmer than average waters): This indicator is monitored using the ROMS model sea surface temperature (SST) data that drives the C-HARM and whale species distribution model predictions. The indicator is triggered when SST was higher than average over the month before evaluation.
2. Low krill (offshore forage) abundance AND high anchovy (inshore forage) abundance: This indicator is monitored using NOAA survey data and is triggered when the following occur simultaneously: krill abundance is below average and anchovy abundance is above average.
3. Whales are concentrated inshore based on NOAA survey data: This indictor is monitored using the simulated NOAA survey data described in Alternate Strategy #2. The indicator is triggered when there is a higher than average density of whales inshore.

**3. Management measures toolbox (MMT):**

Management actions should be commensurate with the risk level and based on the best available science. The settlement specifies the following management measures:

1. Modification of fishing season and allowable fishing areas (i.e., space-time closures): When a RAMP risk assessment determines that there is an elevated risk of whale entanglement in a district, the district is closed to fishing until a subsequent RAMP assessment identifies a low risk of entanglement.
2. Spatially explicit trap limits (total or per-vessel) *(not evaluated)*
3. Requirement of specialized gear (e.g., ropeless gear) *(not evaluated*

**4. Extra season closure stipulations**

The season for Districts 10, 17, and south will close April 1 unless the March 15 risk assessment indicates low risk of entanglement.