Outflow Abundance Candidate Models

Model 1 – Coulston Model 1

Detection: The probability of adult Delta Smelt detection in FMWT samples is primarily a function of (in no particular order) water clarity, station depth, prior (summer) abundance, and fish size distribution.

The presumed functional relationship (linear) is that as transparency increases the probability of capture declines due to gear avoidance. Sampling is conducted using oblique tows for a fixed length of time, such that the amount tow time at any given water column strata decreases as station depth increases. Given that Delta Smelt tend to be concentrated near the surface, the probability of detection would be expected to decrease linearly as station depth increases. Presumably the probability of fall detection would increase linearly as the index of summer abundance derived STN increases. Early in the season the fish are generally small, and have a relatively low probability of being retained in the gear. As the fish grow through the season a greater percentage of the population reaches retainable size. Thus, there tends to be a sigmoidal relationship between mean size and detection probability.

Detection: **Secchi Depth (negative linear), fish length (sigmoidal), Depth (negative linear), STN Index (linear)**

Survival: Survival during the Fall is expected to be a function of habitat quality and the condition of the fish as Fall begins.

The size of the fish as they enter the potentially limiting Fall period maybe a factor in survival through the Fall. It is hypothesized that larger fish will survive at higher rates than smaller fish and the relationship between summer size and fall survival is linear. Fall water temperature, particularly early Fall, is potentially a limiting factor for Delta Smelt, particularly in more landward regions/sub-regions. Higher temperatures are expected to result in lower survival due to higher metabolic demands, and possibly becoming acutely lethal at some times and locations. The expected functional relationship is negatively sigmoidal. Through-sub-region net freshwater flow – It is assumed that monthly relative net (seaward) flow (net flow/region volume) (transport rate?) through the regions and sub-regions can be obtained through modelling, or data mining existing model runs. For this analysis net flow is presumed to be acting as a general surrogate for habitat characteristics for which there is insufficient data. These unmeasured factors might include contaminant levels, microcystis densities, nutrient levels. It is expected there will be interactions with salinity. In general, the presumed functional relationship with survival is positive and linear. Food density and quality is expected to affect survival through size and fitness (predator avoidance, volitional movement capability, etc.) and providing for the metabolic demands of high temperatures. In general the expected relationship between prey density/quality and survival is positive and linear.

Survival: **Prey abundance (linear), STN FL (linear), Fall Temperature (negative sigmoidal), Fall net flow (linear)**

Movement: During the fall Delta Smelt could potentially make either volitional movements among regions/sub-regions(e.g. associated with pursuit of better prey conditions) or be transported by net flow conditions.

Presumable net flows can be derived from models or from mining existing model outputs. The expected effect of flows would be to move fish in the direction of net flow in proportion to the volume of net flow to sub-region volume. During the fall turbidities are unlikely to reach high levels unfavorable for Delta

Smelt, so in general expected movement would be from more transparent (less turbid) to less transparent (more turbid) sub-regions in roughly a linear relationship.

Movement: **Net Flow (linear), Secchi Depth (linear)**

Model 2 – Coulston Model 2

Detection: The probability of adult Delta Smelt detection in FMWT samples is primarily a function of (in no particular order) water clarity, station depth, prior (summer) abundance, and fish size distribution.

The presumed functional relationship (linear) is that as transparency increases the probability of capture declines due to gear avoidance. Sampling is conducted using oblique tows for a fixed length of time, such that the amount tow time at any given water column strata decreases as station depth increases. Given that Delta Smelt tend to be concentrated near the surface, the probability of detection would be expected to decrease linearly as station depth increases. Presumably the probability of fall detection would increase linearly as the index of summer abundance derived STN increases. Early in the season the fish are generally small, and have a relatively low probability of being retained in the gear. As the fish grow through the season a greater percentage of the population reaches retainable size. Thus, there tends to be a sigmoidal relationship between mean size and detection probability.

Detection: **Secchi Depth (linear), fish length (sigmoidal), depth (negative linear), STN Index (linear)**

Survival: Survival during the Fall is expected to be a function of habitat quality and the condition of the fish as Fall begins.

The size of the fish as they enter the potentially limiting Fall period maybe a factor in survival through the Fall. It is hypothesized that larger fish will survive at higher rates than smaller fish and the relationship between summer size and fall survival is linear. Fall water temperature, particularly early Fall, is potentially a limiting factor for Delta Smelt, particularly in more landward regions/sub-regions. Higher temperatures are expected to result in lower survival due to higher metabolic demands, and possibly becoming acutely lethal at some times and locations. The expected functional relationship is negatively sigmoidal. Through-sub-region net freshwater flow – It is assumed that monthly relative net (seaward) flow (net flow/region volume) (transport rate?) through the regions and sub-regions can be obtained through modelling, or data mining existing model runs. For this analysis net flow is presumed to be acting as a general surrogate for habitat characteristics for which there is insufficient data. These unmeasured factors might include contaminant levels, microcystis densities, nutrient levels. It is expected there will be interactions with salinity. In general, the presumed functional relationship with survival is positive and linear. Food density and quality is expected to affect survival through size and fitness (predator avoidance, volitional movement capability, etc.) and providing for the metabolic demands of high temperatures. In general the expected relationship between prey density/quality and survival is positive and linear.

Survival: **Prey abundance (linear), STN FL (linear), Fall Temperature (negative sigmoidal), Fall net flow (linear)**

Movement: During the fall Delta Smelt could potentially make either volitional movements among regions/sub-regions(e.g. associated with pursuit of better prey conditions or water temperatures).

During the fall turbidities are unlikely to reach high levels unfavorable for Delta Smelt, so in general expected movement would be from more transparent (less turbid) to less transparent (more turbid) sub-regions in roughly a linear relationship. Fall water temperature, particularly early Fall, is potentially a limiting factor for Delta Smelt, particularly in more landward regions/sub-regions. Higher temperatures might be expected to result in net volitional movement away from higher temperature sub-regions. During warm periods (like early fall) rates of movement would likely be linearly related to temperature differences between sub-regions.

Movement: **Secchi Depth (negative linear), Temperature (negative linear)**

Model 3 – Bever et al 2016

Detection: Detection probabilities are significantly affected by water clarity, size of the fish, Delta smelt surface orientation, and time of day.

Detection probability increases as water clarity decreases. The smelt are more likely to be captured by the net at a midrange of lengths. Deeper stations result in shorter sampling time at the 4m extent of Delta smelt vertical distribution. Delta smelt disperse out of the range of the nets at slack tides while ebb and flood tides capture them as they use tidal surfing.

Detection: **Secchi Depth (negative linear), fish length (sigmoidal), sample volume at 4m (linear), Tide (Ebb, Flood, and Slack)**

Survival: With increased prey densities, lower predation densities, and reduced reduces the energy cost of moving into brackish water resulting in greater growth and survival.

Salinity is stressful and increases stress and risk of mortality. Smelt prefer turbid water as it improves foraging success and refuge from predation but too turbid and it negatively impacts foraging and gill function.

Survival: **Salinity (negative linear) Secchi Depth (negative quadratic)**

Movement: Delta smelt are poor swimmers therefore they move to areas of low tidal velocity so that they can maintain position at lower salinity stress.

Delta smelt are poor swimmers and are driven out of high velocity areas. Delta smelt seek optimal temperature to reduce stress.

Movement: **Tidal Velocity (negative linear), Salinity (negative linear)**

Model 4 – USFWS BiOp

Detection: Detection probabilities are significantly affected by water clarity, size of the fish, Delta smelt surface orientation, and when sampling occurs relative to the tidal cycle.

Detection probability increases as water clarity decreases. The smelt are more likely to be captured by the net at a midrange of lengths. Deeper stations result in shorter sampling time at the 4m extent of Delta smelt vertical distribution. Delta smelt disperse out of the range of the nets at slack tides while ebb and flood tides capture them as they use tidal surfing.

Detection: **Secchi Depth (negative linear), fish length (sigmoidal), sample volume at 4m (linear), Tide (Ebb, Flood, and Slack)**

Survival: Poor prey abundance and increasingly negative OMR increases entrainment and reduces survival of Delta smelt.

Negative OMR will draw Delta smelt into the south Delta resulting in increased mortality due to entrainment. The abundance of zooplankton has a positive relationship.

Survival: **OMR (linear), Prey (log), Region (Categorical)**

Movement: Although Delta smelt are turbidity seeking if X2 increases it will orient Delta smelt eastward especially after first Flush and increase their susceptibility to OMR.

Delta smelt are turbidity seeking as it promotes predator avoidance and foraging success. After the First Flush event Delta smelt disperse throughout the Suisun/Delta. Highly negative OMR can draw Delta smelt to the south Delta. Delta smelt prefer to remain in the low salinity zone in the Fall.

Movement: **Secchi Depth (linear), X2 (linear), OMR (negative linear), First flush (categorical)**

Model 5 – Manly et al 2014

Detection: Detection probabilities are significantly affected by water clarity, size of the fish, Delta smelt surface orientation, and when sampling occurs relative to the tidal cycle.

Detection probability increases as water clarity decreases. The smelt are more likely to be captured by the net at a midrange of lengths. Deeper stations result in shorter sampling time at the 4m extent of Delta smelt vertical distribution. Delta smelt disperse out of the range of the nets at slack tides while ebb and flood tides capture them as they use tidal surfing.

Detection: **Secchi Depth (negative linear), fish length (sigmoidal), sample volume at 4m (linear), Tide (Ebb, Flood, and Slack)**

Survival: Survival is greater in certain regions over others especially due to increased prey abundance and optimal turbidity.

Smelt prefer turbid water as it improves foraging success and refuge from predation but too turbid and it negatively impacts foraging and gill function. Smelt will more likely survive if prey is increasingly abundant. Certain regions of the Suisun/Delta are more favorable for survival.

Survival: **Prey Abundance (linear), Secchi Depth (negative quadratic), Region (categorical)**

Movement: Delta smelt randomly move but then are more likely to increase their dispersion closer to the end of the year and their spawning season.

Delta smelt will change from their foraging behavior randomly seeking prey to spawning behavior as they get near to the spawning season.

Movement: **Julian day in December (linear)**

Model 6 – Hamilton 1

Detection: Detection probabilities are significantly improved with reduced water clarity, optimal size range for the survey, shallower stations, and previous abundance.

Detection probabilities will increase at low water clarity. The smelt will recruit better into the net at a range of lengths. Deeper stations result in shorter sampling time at shallow depths. There is a biannual pattern to the probability of being detected.

Detection: **Secchi Depth (negative linear), fish length (sigmoidal), depth (negative linear), $FMWT_{t-1}$ (linear)**

Survival: Food dynamics are significant drivers of survival and vary by region.

The abundance of predators has a negative non-linear relation with survival while zooplankton has a positive log relationship. Competitors will have a negative effect on survival as they reduce foraging success. Competition and predation pressure as well as foraging success vary by region.

Survival: **Predator (negative sigmoidal), Prey Abundance (log), Competitors (negative linear), Region (categorical)**

Movement: Delta smelt tend to be in areas of previous occupancy and tend not to move in the Fall from areas that have relatively larger proportion of wetlands and shoal/channel transition especially if the prey mediated turbidity field is greater than the adjacent area.

Delta smelt are more likely to move to higher prey densities with favorable turbidity. Delta smelt move away from higher salinity. Delta smelt are more likely not to move if they previously occupied that region in the previous time step.

Movement: **Prey x turbidity (negative linear), Month (Ordinal), Salinity (negative sigmoidal), regional occupancy (categorical)**

Model 7 – Hamilton 2

Detection: Detection probabilities are significantly improved with reduced water clarity, optimal size range for the survey, shallower stations, and previous abundance.

Detection probabilities will increase at low water clarity. The smelt will recruit better into the net at a range of lengths. Deeper stations result in shorter sampling time at shallow depths. There is a biannual pattern to the probability of being detected.

Detection: **Secchi Depth (negative linear), fish length (sigmoidal), depth (negative linear), $FMWT_{t-1}$ (linear)**

Survival: Food dynamics are significant drivers of survival and vary by region.

The abundance of predators has a negative non-linear relation with survival while zooplankton has a positive log relationship. Competitors will have a negative effect on survival as they reduce foraging success. Competition and predation pressure as well as foraging success vary by region.

Survival: **Predator (negative sigmoidal), Prey Abundance (log), Competitors (negative linear), Region (categorical)**

Movement: Delta smelt tend to be in areas of previous occupancy and tend not to move in the Fall from areas that have relatively larger proportion of wetlands and shoal/channel transition especially if the prey mediated turbidity field is greater than the adjacent area.

Delta smelt are more likely to move to higher prey densities with favorable turbidity. Delta smelt are less likely to move if the area has high volume of wetlands and Channel/shoal habitat. Delta smelt are more likely not to move if they previously occupied that region in the previous time step.

Movement: **Prey x turbidity (negative linear), Distance from wetland (negative linear), Distance from shoal/channel (negative linear), regional occupancy (categorical**

Model 8 – Feyrer et al 2011

Detection: Detection probabilities are significantly affected by water clarity, size of the fish, Delta smelt surface orientation, and time of day.

Detection probability increases as water clarity decreases. The smelt are more likely to be captured by the net at a midrange of lengths. Deeper stations result in shorter sampling time at the 4m extent of Delta smelt vertical distribution. Delta smelt disperse out of the range of the nets at slack tides while ebb and flood tides capture them as they use tidal surfing.

Detection: **Secchi Depth (negative linear), fish length (sigmoidal), sample volume at 4m (linear), Tide (Ebb, Flood, and Slack)**

Survival: With a larger low salinity zone smelt have access to more favorable conditions of turbidity and prey abundance that increase survival.

The abundance of zooplankton has a positive relationship. Salinity is stressful and increases stress and risk of mortality. Smelt prefer turbid water as it improves foraging success and refuge from predation but too turbid and it negatively impacts foraging and gill function. Temperature is a significant stressor that increases the risk of mortality.

Survival: **Prey Abundance (linear), Salinity (negative linear), Secchi Depth (quadratic), Temperature (negative sigmoidal)**

Movement: Delta smelt move away from higher salinity.

Salinity is a significant stressor and Delta smelt move to reduce their stress. Movement: **Salinity (negative linear)**

Model 9 – Food Driven

Detection: Detection probabilities are significantly affected by water clarity, size of the fish, Delta smelt surface orientation, and when sampling occurs relative to the tidal cycle.

Detection probability increases as water clarity decreases. The smelt are more likely to be captured by the net at a midrange of lengths. Deeper stations result in shorter sampling time at the 4m extent of Delta smelt vertical distribution. Delta smelt disperse out of the range of the nets at slack tides while ebb and flood tides capture them as they use tidal surfing.

Detection: **Secchi Depth (negative linear), fish length (sigmoidal), sample volume at 4m (linear), Tide (Ebb, Flood, and Slack)**

Survival: With a larger salinity zone smelt can more freely move to preferred areas away from high predation pressure to areas where foraging success is greater due to increased prey and turbidity which ultimately increases survival.

Delta smelt are primarily food driven therefore survival is promoted in regards to mechanism that affect feeding success and need. The abundance of competitors has a negative relation with survival while zooplankton has a positive relationship. Smelt prefer turbid water as it improves foraging success and refuge from predation but too turbid and it negatively impacts foraging and gill function. Temperature will determine Delta smelt bioenergetic needs

Survival: **Competitor abundance (negative sigmoidal), Prey Abundance (linear), Temperature (negative sigmoidal), Secchi Depth (quadratic)**

Movement: Delta smelt movement is food and salinity driven until after the first flush where movement is towards spawning grounds.

Delta smelt are primarily food driven therefore movement behavior is based on optimizing foraging success and reducing nutritional stress. Delta smelt are more likely to move if prey is relatively low. Delta smelt seek optimal temperature to reduce stress. After the first flush spawning behavior dominants and Delta smelt move toward spawning habitat.

Movement: **Prey abundance (negative linear), Salinity (linear), First Flush (categorical)**

Model 10 – Flow driven

Detection: Detection probabilities are significantly affected by water clarity, size of the fish, Delta smelt surface orientation, and when sampling occurs relative to the tidal cycle.

Detection probability increases as water clarity decreases. The smelt are more likely to be captured by the net at a midrange of lengths. Deeper stations result in shorter sampling time at the 4m extent of Delta smelt vertical distribution. Delta smelt disperse out of the range of the nets at slack tides while ebb and flood tides capture them as they use tidal surfing.

Detection: **Secchi Depth (negative linear), fish length (sigmoidal), sample volume at 4m (linear), Tide (Ebb, Flood, and Slack)**

Survival: With a larger low salinity zone smelt have access to more favorable conditions of turbidity and prey abundance that increase survival.

Mechanisms relating to flow drive Delta smelt survival. Increasingly negative OMR flows increases entrainment risk of Delta smelt. Temperature is a significant stressor that increases the risk of mortality. Greater net outflow increases beneficial factors and reduce stressors.

Survival: **OMR (linear), Fall Temperature (negative sigmoidal), Fall Outflow (linear),**

Movement: Delta smelt distribute around the low salinity zone and are more likely to move to relatively higher turbidity but can be drawn into the south Delta with highly negative OMR after the first flush event.

Mechanisms relating to flow drive Delta smelt movement. Delta smelt are poor swimmers and are driven out of high velocity areas. Delta smelt prefer to remain in the low salinity zone in the Fall. After the First Flush event Delta smelt disperse throughout the Suisun/Delta. Highly negative OMR can draw Delta smelt to the south Delta.

Movement: **Distance from X2 (negative linear), Tidal velocity (negative linear), First Flush (categorical), OMR (negative linear)**

Model 11 – Niche Optimization

Detection: Detection probabilities are significantly affected by water clarity, depth of the station, and when sampling occurs relative to sunrise.

Detection probability increases as water clarity decreases. . Deeper stations result in shorter sampling time at the 4m extent of Delta smelt vertical distribution. Delta smelt disperse out of the range of the nets at slack tides while ebb and flood tides capture them as they use tidal surfing. Delta smelt are crepuscular and disperse into the range of the nets during sunrise and sunset.

Detection: **Secchi Depth (negative linear), sample volume at 4m (linear), Time from sunrise (negative quadratic), Tide (Ebb, Flood, and Slack)**

Survival: Survival is poorer due to reduced prey abundance.

Smelt will more likely survive if prey is increasingly abundant.

Survival: **Prey Abundance (linear),**

Movement: Delta smelt are always seeking optimal water quality.

Delta smelt are primarily driven to seek optimal water quality conditions. Delta smelt are turbidity seeking as it promotes predator avoidance and foraging success. Delta smelt seek optimal temperature to reduce stress. Delta smelt seek fresh and low salinity as they are adapted to those ranges of salinity.

Movement: **Secchi Depth (Linear), Salinity (sigmoidal), temperature (linear)**

Model 12 – Spatial

Detection: Detection probabilities are significantly affected by water clarity, depth of the station, and when sampling occurs relative to sunrise.

Detection probability increases as water clarity decreases. . Deeper stations result in shorter sampling time at the 4m extent of Delta smelt vertical distribution. Delta smelt disperse out of the range of the nets at slack tides while ebb and flood tides capture them as they use tidal surfing. Delta smelt are crepuscular and disperse into the range of the nets during sunrise and sunset.

Detection: **Secchi Depth (negative linear), sample volume at 4m (linear), Time from sunrise (negative quadratic), Tide (Ebb, Flood, and Slack)**

Survival: Survival is greater in certain regions over others especially due to increased prey abundance and optimal turbidity.

Salinity is stressful and increases stress and risk of mortality. Smelt will more likely survive if prey is increasingly abundant. Certain regions of the Suisun/Delta are more favorable for survival.

Survival: **Prey Abundance (linear), X2 (quadratic), Region (categorical)**

Movement: Delta smelt distribute around the low salinity zone and are more likely to move to relatively higher turbidity but can be drawn into the south Delta with highly negative OMR after the first flush event.

Exports can draw Delta smelt into the south Delta. Delta smelt are turbidity seeking as it promotes predator avoidance and foraging success. Delta smelt are poor swimmers and are driven out of high velocity areas.

Movement: **Exports (linear), Secchi Depth (linear), Tidal velocity (linear)**