Memo

To: CSAMP Delta Smelt SDM Technical Working Group (TWG)

From: Brian Crawford and Sally Rudd, Compass Resource Management

Date: December 1, 2021

Re: Dynamic Habitat Tool Summary and User Guide

1 Background & Purpose of Dynamic Habitat Tool

The current phase (Phase 3) of CSAMP's Delta Smelt Structured Decision Making (SDM) project will identify potential portfolios of management actions that can advance Delta Smelt recovery and evaluate the effects of these portfolios Delta Smelt population outcomes, as well as other social, ecological, and economic objectives. In Phase 2 of the SDM project, the TWG identified lack of suitable dynamic habitat as a key bottleneck for Delta Smelt that could be addressed through strategic management actions.

We refer to "**dynamic habitat**" as the overlap of suitable temperature, turbidity, salinity, and food conditions in space and time. "Suitable" conditions reflect threshold values informed by published studies and expert judgment.

The Technical Working Group (TWG) Dynamic Habitat Sub-group has been working with Compass to build a tool that can inform a deliberative process where the TWG will specify distinct management opportunities and action portfolios that increase the overlap of suitable dynamic habitat. The tool will inform the following key questions:

- *What habitat attribute(s) are most often unsuitable in specific subregions or across the Delta? This may inform spatial targets for management intervention.*
- *What habitat attribute(s) are most often unsuitable within each time period/life stage across the year? This may inform temporal targets for management intervention.*
- *How often do suitable ranges of all four dynamic habitat attributes overlap in each subregion in the Delta under lower and higher flow year-types?*
- *How much does the choice of a threshold value separating more or less suitable conditions (e.g., a temperature threshold of 17 or 18 °C) influence results (i.e., the frequency an attribute was "suitable")?*

The development of this tool was informed by input from the TWG during meetings on May 7 and July 29, 2021, and the Dynamic Habitat Sub-group during two additional meetings. The first Sub-group meeting focused on reviewing information from 17 studies (synthesized by Compass) that reported values relating to suitable ranges of habitat attributes for delta smelt (see Section 4: Appendix). The Sub-group discussed the difficulty in selecting specific "thresholds" that separate better and worse conditions for smelt, and that this transition can be more gradual for certain habitat attributes and life stages. The Sub-group also highlighted the need to consider if reported values came from field vs. lab studies and specifically what was measured (e.g., limits to growth, survival). After this meeting, Compass had two meetings with Scott Hamilton to discuss options for using his affinity analysis and performance analysis to inform thresholds and possible structures for this Dynamic Habitat Tool. Informed by these discussions, Compass adapted a prototype of a Dynamic Habitat Tool in Excel – originally built by Scott – and elicited feedback from the Dynamic Habitat Sub-group during the second meeting, including overall structure and function, how results are summarized and displayed, years of data included, and other aspects of the design. The Sub-group supported developing the tool with flexibility to toggle between different habitat threshold values that are informed by existing scientific studies, summarize conditions across different time frames of interest (1987-2020, or for more recent years, such as 2000-2020), and summarizing conditions for higher vs. lower flow years.

With the TWG's support, Compass used this feedback to fully build out the tool into its current form.

2 Instructions for Using Dynamic Habitat Tool Prototype

2.1 Workbook structure

The Dynamic Habitat Tool in the Excel workbook begins with a "READ ME" worksheet that contains a description of the tool's purpose and brief description and data sources used or contained in each worksheet (Table 1). Importantly, it describes from where original datasets were accessed and any steps Compass took in summarizing data prior to use in the tool.

Table 1. Descriptions of each worksheet in the Delta Smelt Dynamic Habitat Tool (taken from the tool's READ ME worksheet).

Worksheet name	Brief description & data source(s)	Year range
Interface_months sheets	Dynamic habitat tool sheets, grouped by life stage. The tool summarizes historical data to report the frequency of suitable dynamic habitat conditions for delta smelt, based on user-defined suitability thresholds for four habitat attributes (turbidity/clarity, temperature, salinity, and prey density) and a user-defined year range for data to include when summarizing results. Each sheet represents a two-month period that roughly corresponds to the following life stages (starting with the Jan-Feb period): pre-spawning adults, spawning adults, subjuveniles, juveniles, and subadults. Note: the subadult sheet ("Sep-Dec") includes separate periods of Sep-Oct and Nov-Dec where users can define different thresholds for summarizing dynamic habitat conditions.	User-defined
Results_summary	Summary of results from all "Interface" sheets that presents the frequency of suitable dynamic habitat conditions for delta smelt across all two-month periods (and all life stages). Results are summarized for higher and lower flow periods.	User-defined
Data_summary	Summary of sample sizes for each habitat attribute by subregion, month-period, and lower and higher flow year types.	1987-2020
Data	This is the main data table that contains measured conditions of dynamic habitat attributes that are summarized by the tool in the Interface worksheets. Each row represents daily average conditions for water quality attributes (turbidity/clarity, temperature, salinity), as well as daily average conditions for prey density (accessed from the "Zoop" worksheet) and Delta outflow. These mean daily conditions for water quality and zooplankton came from original datasets that included measured values per sample, and included between 0 and 39 (for water quality data) and 0 to 6 (for zooplankton data) samples per day. Therefore, Compass calculated mean values per day to reduce any bias from varying daily sampling effort. Original water quality data is available on https://github.com/CSAMP/delta-secchi-temperature-data. It includes data from the following sources: EMP (Environmental Monitoring Program), STN (Summer Townet Survey), FMWT (Fall Midwater Trawl), EDSM (Enhanced Delta Smelt Monitoring), DJFMP (Delta Juvenile Fish Monitoring Program), 20mm (20mm Survey), SKT (Spring Kodiak Trawl), Bay Study, USGS San Francisco Bay Surveys), USBR (United	1987-2020

	States Bureau of Reclamation Sacramento Deepwater Ship Channel data), and Suisun Marsh Fish Study.	
Zoop	Zooplankton data (taxa-specific biomass) was developed from the IEP's integrated zooplankton dataset, accessed through the zooper package in R, available on the IEP's GitHub site (https://github.com/InteragencyEcologicalProgram/zooper). We had input from Arthur Barros (IEP) and Wim Kimmerer (SFSU) regarding 1) which taxa to include as prey in our analysis, and 2) taxa-specific conversion rates for calculating biomass (µgC/m3) from the available zooplankton catch per unit effort (CPUE) data in the IEP dataset. For mysid taxa, Arthur Barros provided Compass biomass data directly for mysid/amphipod taxa, as well as the taxa-specific length-weight conversions used to calculate biomass from CPUE. Note: The first row in the sheet (in Columns H through BF) allows users to turn on or off specific taxa to include when summarizing total biomass per day, which is used to calculate average prey density conditions.	1987-2017
Flow_lookup	Lookup table for historical daily flow data (Dayflow data of net Delta outflow as measured past Chipps Island to San Francisco Bay). Available on https://data.cnra.ca.gov/dataset/dayflow. This sheet also records the flow type (high vs. low) for each 2-month period – calculated by comparing the year-specific flow within a 2-month period to the median flow for that 2-month period across all years.	1987-2020
Delta_smelt_ lookup	Lookup table for delta smelt distributions by subregion, 2-month period, and year - as calculated by Will Smith in the IBMR analysis from 20-mm, Midwater Trawl, and Spring Kodiak Surveys. The sheet includes the percentage of delta smelt distributed in each subregion within high vs. low flow years, based on flow indicators in the Flow_lookup sheet. Methods and data available at https://github.com/CSAMP/fish-distribution-data	1995-2014

2.2 Using the tool

Each "Interface" worksheet (i.e., the Dynamic Habitat Tool) focuses on a life stage (broken into 2-month periods) and involves two steps: (1) specifying inputs for habitat attribute thresholds and year range for summarizing conditions, and (2) examining patterns of suitable habitat overlap displayed in tables.

Step 1) Manipulate input cells in green (Fig 1)

1a) Users can change the beginning and ending years in cells B8 and B9 to use when summarizing habitat conditions from historical data. These values must be between 1987 and 2020.

1b) Users can input threshold values for each habitat attribute (temperature, turbidity, salinity, and prey density), which represent the points at which conditions transition from "more suitable" to "less suitable" for delta smelt (in terms of growth, survival, occurrence, etc.) for each life stage / 2-month period. For example, the user can input a temperature value indicating the upper limit where conditions become less suitable for spawning adults.

- For this tool, "thresholds" represent values where management intervention could be beneficial if a habitat attribute tends to be below or above the threshold at a given space and time. Targeted management would be a lower priority under more suitable conditions. We acknowledge that transitions between "more" and "less" suitable conditions for delta smelt for an attribute is often gradual (e.g., the more prey, the better), and for this reason, the tool allows for testing multiple thresholds to understand how the choice of thresholds affects conclusions on where management intervention could be beneficial.

1c) Users can review the figures on the right side of the sheet (starting in column S) that show reference thresholds from published studies that can inform the selection of thresholds. See Section 4: Appendix for more details on these studies.

Delta Smelt Dynamic Habitat Analysis Tool

Life Stage: Pre-spawn adults (Jan-Feb)

Inputs

Begin year:	1987	<--default: 1987
End year:	2020	<--default: 2020
Median Flow:	18,460	cfs

Thresholds	Low	High	
Clarity		40	cm
Temp		20	°C
Salinity	0	2,000	µS/cm
Food	300		µgC/m³

Note: "High" threshold values indicate the highest point where conditions are suitable.
i.e., suitable conditions are lower than this "High" threshold.
"Low" threshold values indicate the lowest point where conditions are suitable.
i.e., suitable conditions are higher than this "Low" threshold.

Figure 1. Screenshot of Step 1 for the Delta Smelt Dynamic Habitat tool where users can adjust values in green cells for (1) the year range for summarizing habitat conditions and (2) threshold values for each habitat attribute.

Step 2) Examine summary results

Based on the year and threshold value inputs, the tool summarizes historical data and calculates the proportion of sampled days where average conditions for each attribute were "more suitable", given each subregion and flow condition. The results are displayed in tables (Fig 2). Because the input and results cells are linked, the interface allows users to see in real time how choosing different threshold values or year ranges influences the degree of suitable conditions and overlap by subregion (see Fig 3).

Results

HIGHER FLOW - JULY & AUGUST

Subregion	Clarity OK	Temp OK	Salinity OK	Prey OK	Smelt Distr. (1995-2014)
Yolo/Cache	25%	37%	100%	100%	8.2%
Upper Sacramento	4%	85%	100%	73%	0.1%
East Delta	1%	58%	100%	46%	0.1%
South Delta	32%	26%	100%	100%	0.1%
Lower Sacramento	31%	68%	100%	86%	7.8%
Lower San Joaquin	2%	47%	100%	99%	2.0%
Confluence	39%	72%	99%	93%	11.3%
Suisun Marsh	88%	66%	89%	90%	2.9%
NE Suisun	76%	89%	79%	61%	12.2%
SE Suisun	51%	84%	93%	77%	14.4%
NW Suisun	86%	90%	38%	80%	37.6%
SW Suisun	64%	95%	27%	64%	3.3%

Table: Clarity, temp, salinity and prey columns show the percentage of sampled days across Jul-Aug periods that each of the four attributes were "more suitable". The last column shows proportion of delta smelt observations. All results by subregion in HIGHER FLOW Jul-Aug periods.

LOWER FLOW - JULY & AUGUST

Subregion	Clarity OK	Temp OK	Salinity OK	Prey OK	Smelt Distr. (1995-2014)
Yolo/Cache	24%	26%	100%	100%	18.4%
Upper Sacramento	9%	66%	100%	73%	0.1%
East Delta	1%	29%	100%	55%	0.2%
South Delta	42%	7%	100%	100%	0.2%
Lower Sacramento	51%	81%	99%	87%	38.2%
Lower San Joaquin	7%	51%	100%	100%	7.2%
Confluence	46%	86%	99%	82%	11.6%
Suisun Marsh	67%	75%	33%	70%	1.1%
NE Suisun	70%	94%	17%	57%	9.1%
SE Suisun	40%	94%	41%	63%	10.3%
NW Suisun	72%	98%	2%	85%	3.4%
SW Suisun	56%	99%	2%	65%	0.1%

Table: Clarity, temp, salinity and prey columns show the percentage of sampled days across Jul-Aug periods that each of the four attributes were "more suitable". The last column shows proportion of delta smelt observations. All results by subregion in LOWER FLOW Jul-Aug periods.

Figure 2. Screenshot of the Delta Smelt Dynamic Habitat tool where results are displayed in tables showing the proportion of sampled days across years that habitat attributes were suitable for higher flow (left) and lower flow (right) years.

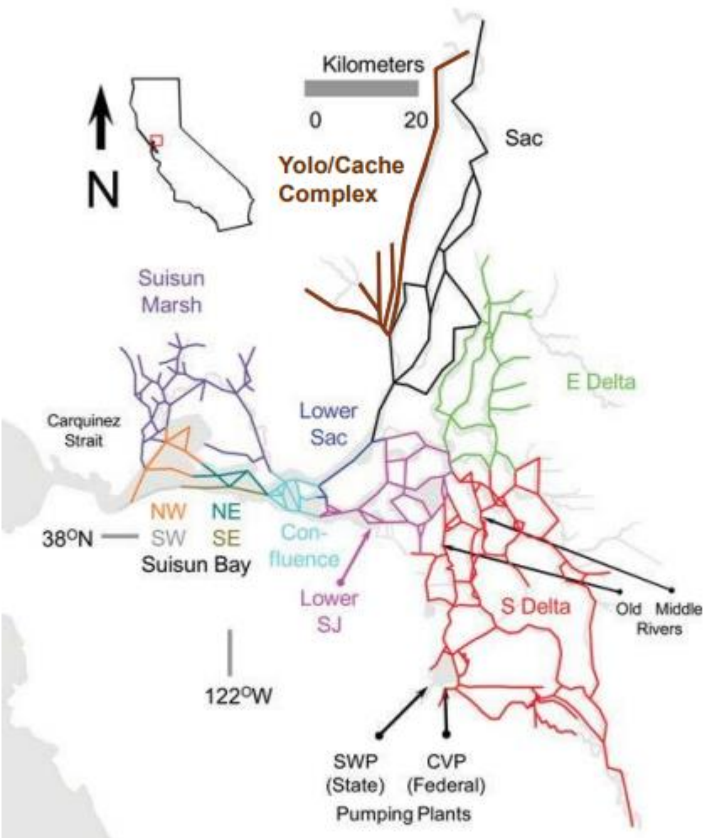

Figure 3. Map of 12 delta subregions (from Rose et al. 2013) used in the Dynamic Habitat Tool to summarize the proportion of sampled days habitat attributes were suitable.

3 Appendix: Threshold Figures

To aid users in choosing threshold values in the tool, Compass developed “threshold figures” for each life stage based on the literature review that was undertaken before Dynamic Habitat Sub-group Meeting #1. Table 2 provides a compilation of published studies and reports identified to date that investigated relationships between the four habitat attributes and delta smelt occurrence, growth, and survival. The table is divided into two sections – the first section identifies all studies referenced in the threshold figures in the Dynamic Habitat Tool and the second section identifies the studies that were not included in the threshold figures. Although all studies explored relationships between delta smelt outcomes and habitat attributes, Compass did not include studies in the threshold figures if findings were inconclusive for determining thresholds (e.g., there was no effect to smelt across the range of habitat conditions tested in lab trials).

The threshold figures (Figs 4a-e at the end of the document) show values extracted from delta smelt habitat attribute studies (blue dots). Included in the threshold figures are possible values identified by Scott based on his unpublished performance analysis – these are referenced as “Ham 2021” and Scott is welcoming feedback and discussion around these possible thresholds. Also on Scott’s suggestion, we included the distribution of delta smelt catch across the habitat attribute value range (shaded blue area) from field data collected between 1987 and 2014.

Table 2: List of reviewed studies on suitable habitat ranges for delta smelt and what thresholds were extracted for use in a tool for assessing dynamic habitat overlap and specifying management actions. Any table or figure number in the "Details" column refers to the study (and not this document).

Study	Habitat attributes assessed	Life stages	Field or lab data	Details for extracted thresholds
Included in threshold figures				
Baskerville-Bridges et al. 2004	Turbidity	Larvae	Lab	The study used lab trials to measure smelt feeding rates across different turbidity treatments. We extracted the treatment value (10 NTU, or ~ 53cm Secchi depth) as the threshold where feeding rates were lower for larvae, relative to more turbid treatments. See Figure 2.
Bever et al. 2016	Turbidity, salinity	Subadults, adults	Field	The study used correlational analyses to estimate relationships between smelt catch indices and habitat attributes. Authors displayed relationships and specified thresholds that generally represented cutoffs at the 25-50 percentile of catch index. Figures 5, 6.
Hamilton 2021 (unpubl. study)	Temp, turbidity, salinity, prey	All	Field	Scott Hamilton used a performance analysis to identify the worst values for habitat attributes during years where the abundance-change ratio (ACR) – similar to population growth rate – met a certain level. These indicated thresholds for "excellent" years (ACR exceeded 8, i.e., an 8-fold increase in abundance), doubling years (ACR exceeded 2, i.e., a doubling in abundance), and no-change years (ACR indicated no abundance change).
Hamilton & Murphy 2020	Temp, turbidity, salinity, prey	All	Field	The study used an affinity analysis (difference between conditions used by smelt and availability of those conditions) to determine ranges of conditions acceptable to delta smelt. We extracted values associated with strong and weak affinity. Strong affinity ("suitable habitat") indicated use-availability was significantly positive. Weak affinity ("adequate habitat") indicated use-availability was positive but not significantly different from zero. Weak aversion ("unsuitable habitat") indicated use-availability was negative but not significantly different from zero. See Table 6.
Hasenbein et al. 2016	Turbidity	Sub-juveniles	Lab	The study used lab trials to measure smelt survival, feeding rates, and stress across different turbidity treatments. We extracted the treatment value (12 NTU, or ~ 50cm Secchi depth) as the lower bounds of optimal survival rates. See Figure 1.
Komoroske et al. 2014	Temp, salinity	All	Lab	The study used lab trials to measure smelt thermal and salinity tolerances. For temperature, we extracted the value where 50% morbidity occurred (Figure 2). For salinity, we extracted the highest treatment value, which resulted in no decrease in survival (p. 6).
Komoroske et al. 2015	Temp	Larvae, adults	Lab	The study used lab trials to measure smelt thermal stress. For temperature, we extracted the value where sublethal stress occurred for fish acclimated at the mid temperature treatment (Table 1).
Lewis et al. 2021	Temp, turbidity, salinity	Sub-adults	Field	This study used regression to evaluate the effects turbidity, temperature, and salinity on growth rates via otolith data. Growth rates declined at temperatures >20 degC (Figure 5D). Effects of turbidity and salinity on growth rates were more variable by region and model tested, and thresholds were not extracted.

Rose et al. 2013	Temp	All	Field	The study used an IBM (bioenergetics model) to simulate movement, survival, and reproduction, calibrated to historical data. The model included a function between temperature and consumption rates; it reported temperature thresholds for the lower and upper bounds of max (optimal) consumption and a max limit where consumption declined. See Table 1.
Sommer & Meija 2013	Temp, turbidity, salinity, prey	Not explicitly separated	Field	The study used a combination of literature review and generalized additive models to estimate relationships between habitat attributes and fish occurrence. Author-defined thresholds were based on GAM results (Figure 4), with support from previous studies.
Swanson et al. 2000	Temp, salinity	Juveniles	Lab	The study used lab trials to measure smelt thermal tolerances. For temperature, we extracted the critical thermal maxima (see Table 1). Maximum salinity thresholds far exceeded other studies and were not extracted.
Additional studies not included in threshold figures				
Davis et al. 2019a	Temp	Juveniles	Lab	The study used lab trials to measure smelt predation and anti-predator responses across temp treatments. Predation from LM bass was highest in treatments of 21 degC, relative to 17 degC. Study not included: ambiguous relationship between response variables and thresholds of suitable/unsuitable conditions.
Davis et al. 2019b	Temp, salinity	Juveniles	Lab	The study used lab trials to measure smelt thermal and salinity tolerances. Critical thermal max was 28 and 29 degC when acclimated in 16 and 20 degC water, respectively. Study not included: found that critical thermal max was not influenced by varying salinities.
Eder et al. 2013	Temp	Juveniles, adults	Lab	The study used lab trials to measure consumption rates in 3 temperature treatments. The study found consumption rates were highest at the highest temperature treatment (18 degC). Study not included: authors concluded the upper bounds for an optimal temperature range may be above the study's treatment levels.
Ferrari et al. 2013	Turbidity	Adults	Lab	This mesocosm experiment measured predation rates in clear vs. turbid (34 cm Secchi depth) water. Predation rates were higher in clear water, relative to turbid water. Study not included: only included 2 treatment levels, results ambiguous for selecting specific threshold value of suitable/unsuitable conditions.
Hammock et al. 2017	Salinity, prey	Juveniles-Adults	Field	This study used regression to evaluate the effects of salinity, season, and prey abundance on foraging success. Foraging success was higher in brackish (>0.55 psu) than fresh (<0.55 psu) water, on average, but higher in freshwater in summer. Study not included: results ambiguous relationship between response variables and thresholds of suitable/unsuitable conditions, and threshold of 0.55psu (~ <1,000 µS/cm) is substantially lower than all other studies.
Hammock et al. 2019	Temp, turbidity	Juveniles-Adults	Field	This study used regression to evaluate the effects of GIS-based tidal wetland area, turbidity, and temperature on foraging success. "Stomach fullness inc. with inc. wetland area and inc. water temp, and was reduced at turbidities >80 NTU." Stomach fullness inc. as temp inc. from 7.4 to 25.5 degC. Study not included: results ambiguous for selecting specific threshold value of suitable/unsuitable conditions.
Hammock et al. 2021	Temp, turbidity, salinity, prey	Juveniles-Adults	Field	This study used regression to evaluate the effects of GIS-based tidal wetland area, turbidity, temperature, prey density, and outflow on body condition. Body condition peaked at relatively cool temperatures (10-13 degC). Study not included: results ambiguous for selecting specific threshold value of suitable/unsuitable conditions.

Jeffries et al. 2016	Temp	Juveniles	Lab	The study used lab trials to measure smelt thermal stress. Found no inc. in heat shock proteins in smelt in all treatments. Study not included: no information about potential thresholds.
Komoroske et al. 2016	Salinity	Adults	Lab	The study used lab trials to measure smelt sublethal stress and body condition in salinity treatments. Found decreased body conditions and survival at acute and chronic salinity levels of 34 ppt. Study not included: study included limited treatment levels making it ambiguous to define threshold, and treatment levels where effects were found (34 ppt or ~57,000 µS/cm) were substantially higher than all other studies.

References in Table 2

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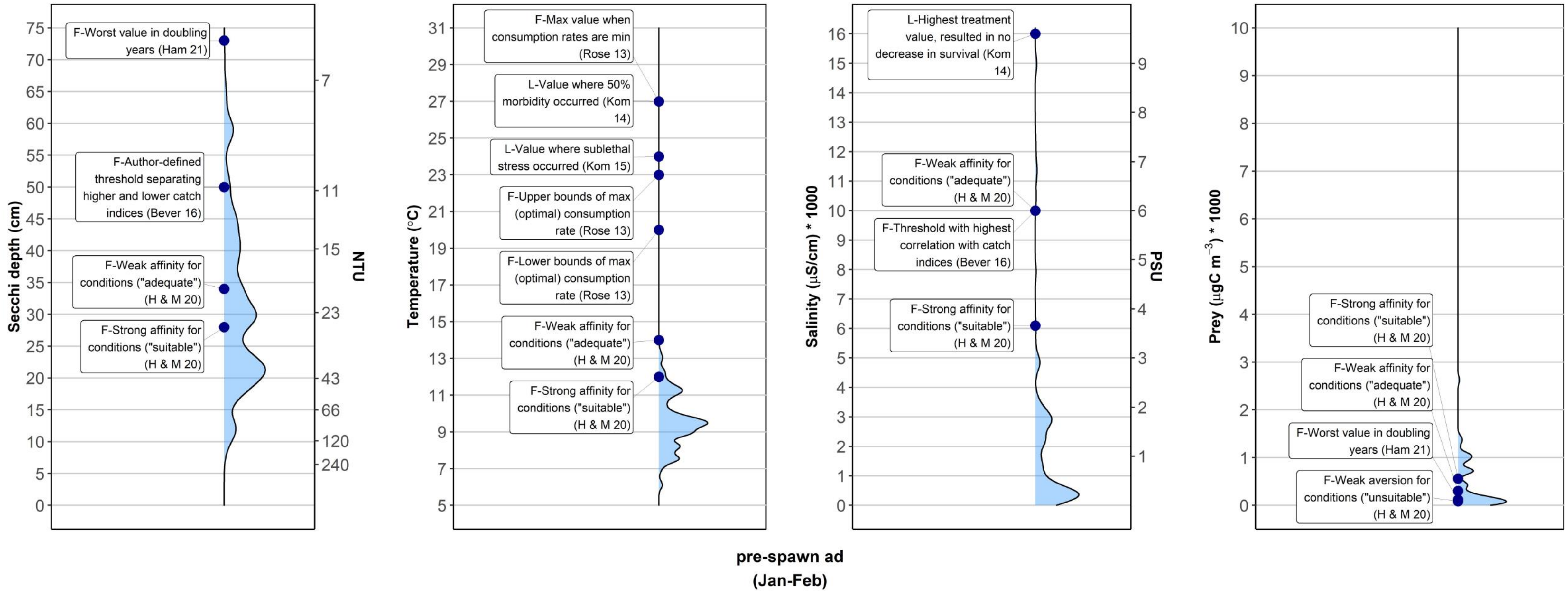

Figure 4a. Threshold Figure for Pre-spawning adults (Jan-Feb). Values extracted from delta smelt habitat attribute studies or proposed by Scott Hamilton using his performance and affinity analyses (blue dots). Study labels identify if the study was based on field (F) or lab (L) data, include brief value descriptions, and abbreviate the study author and year (full references can be found in Table 2). Distribution of delta smelt catch across the habitat attribute value range from field data collected between 1987 and 2014 (shaded blue area). Note that Secchi depth was converted to NTU using values from the Utah State University Extension; for the salinity panels in each figure, 10000 μS/cm = 6 psu (or ppt) following Sommer & Meija (2013) and Wagner et al. (2006).

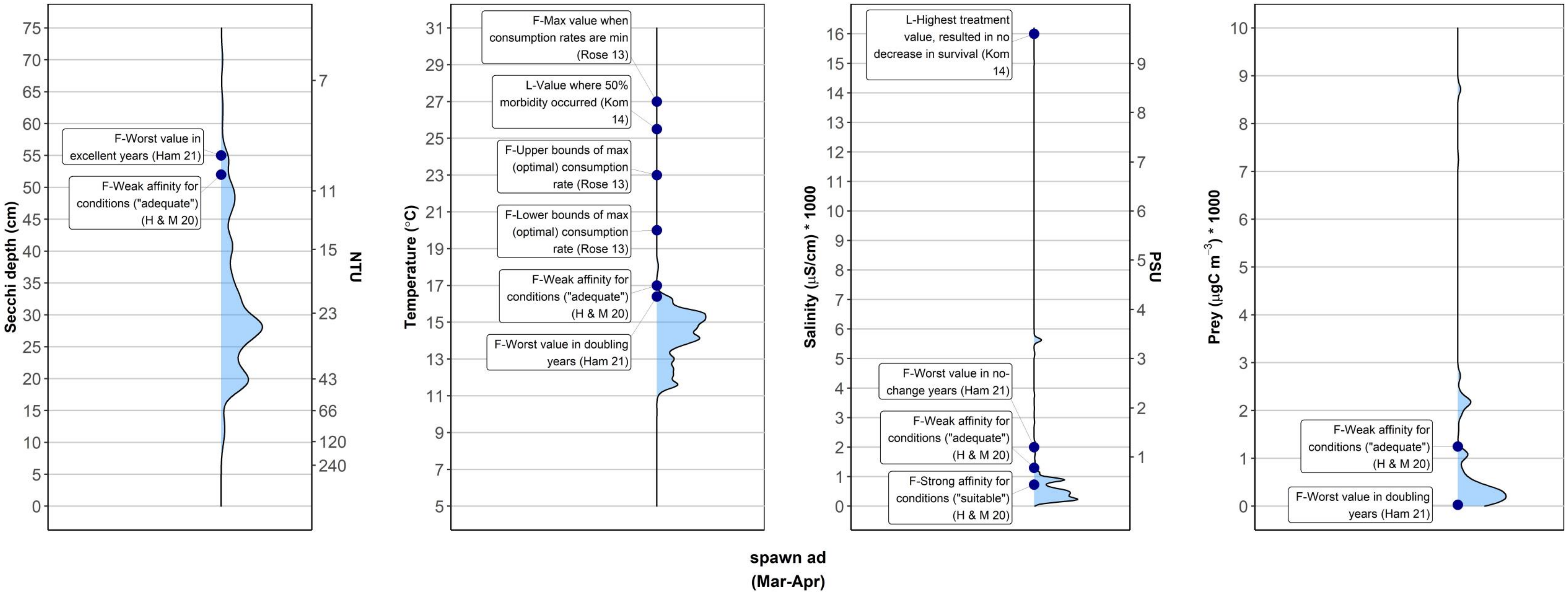

Figure 4b. Threshold Figure for Spawning adults (Mar-Apr). Values extracted from delta smelt habitat attribute studies or proposed by Scott Hamilton using his performance and affinity analyses (blue dots). Study labels identify if the study was based on field (F) or lab (L) data, include brief value descriptions, and abbreviate the study author and year (full references can be found in Table 2). Distribution of delta smelt catch across the habitat attribute value range from field data collected between 1987 and 2014 (shaded blue area). Note that Secchi depth was converted to NTU using values from the Utah State University Extension; for the salinity panels in each figure, 10000 µS/cm = 6 psu (or ppt) following Sommer & Meija (2013) and Wagner et al. (2006).

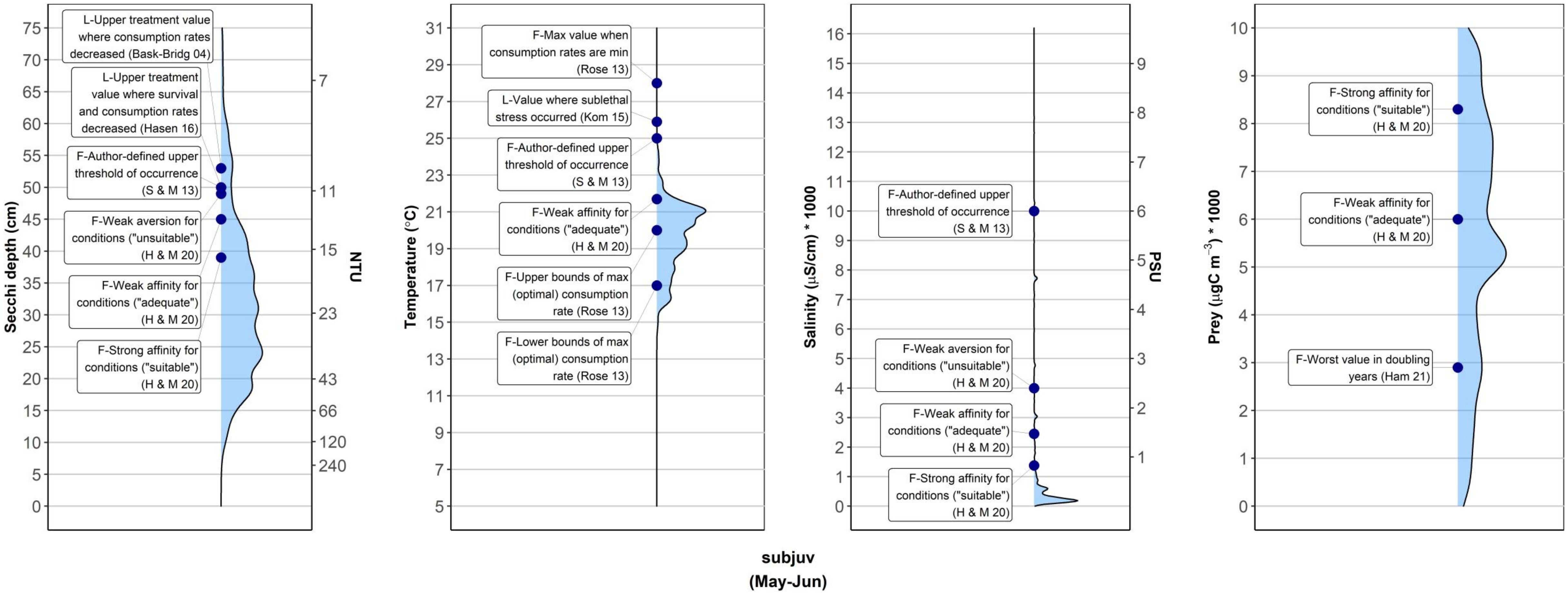

Figure 4c. Threshold Figure for subjuveniles (May-Jun). Values extracted from delta smelt habitat attribute studies or proposed by Scott Hamilton using his performance and affinity analyses (blue dots). Study labels identify if the study was based on field (F) or lab (L) data, include brief value descriptions, and abbreviate the study author and year (full references can be found in Table 2). Distribution of delta smelt catch across the habitat attribute value range from field data collected between 1987 and 2014 (shaded blue area). Note that Secchi depth was converted to NTU using values from the Utah State University Extension; for the salinity panels in each figure, 10000 µS/cm = 6 psu (or ppt) following Sommer & Meija (2013) and Wagner et al. (2006).

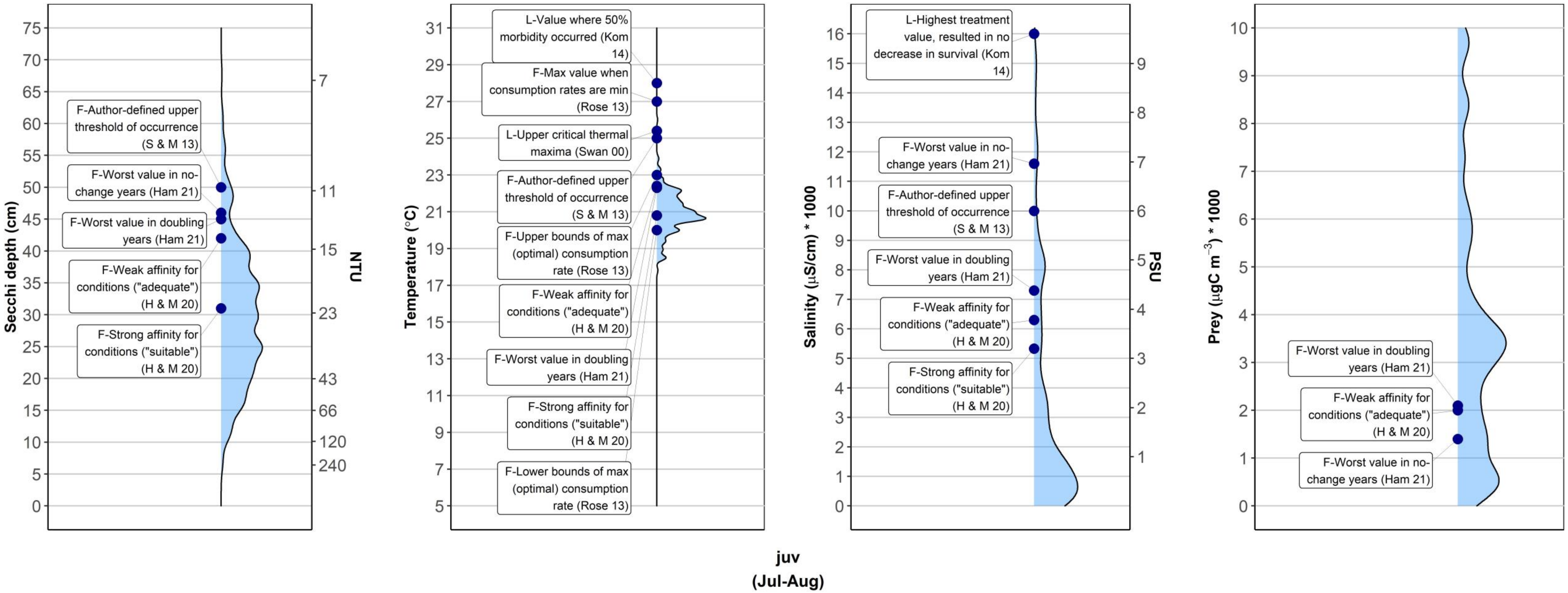

Figure 4d. Threshold Figure for juveniles (Jul-Aug). Values extracted from delta smelt habitat attribute studies or proposed by Scott Hamilton using his performance and affinity analyses (blue dots). Study labels identify if the study was based on field (F) or lab (L) data, include brief value descriptions, and abbreviate the study author and year (full references can be found in Table 2). Distribution of delta smelt catch across the habitat attribute value range from field data collected between 1987 and 2014 (shaded blue area). Note that Secchi depth was converted to NTU using values from the Utah State University Extension; for the salinity panels in each figure, 10000 µS/cm = 6 psu (or ppt) following Sommer & Meija (2013) and Wagner et al. (2006).

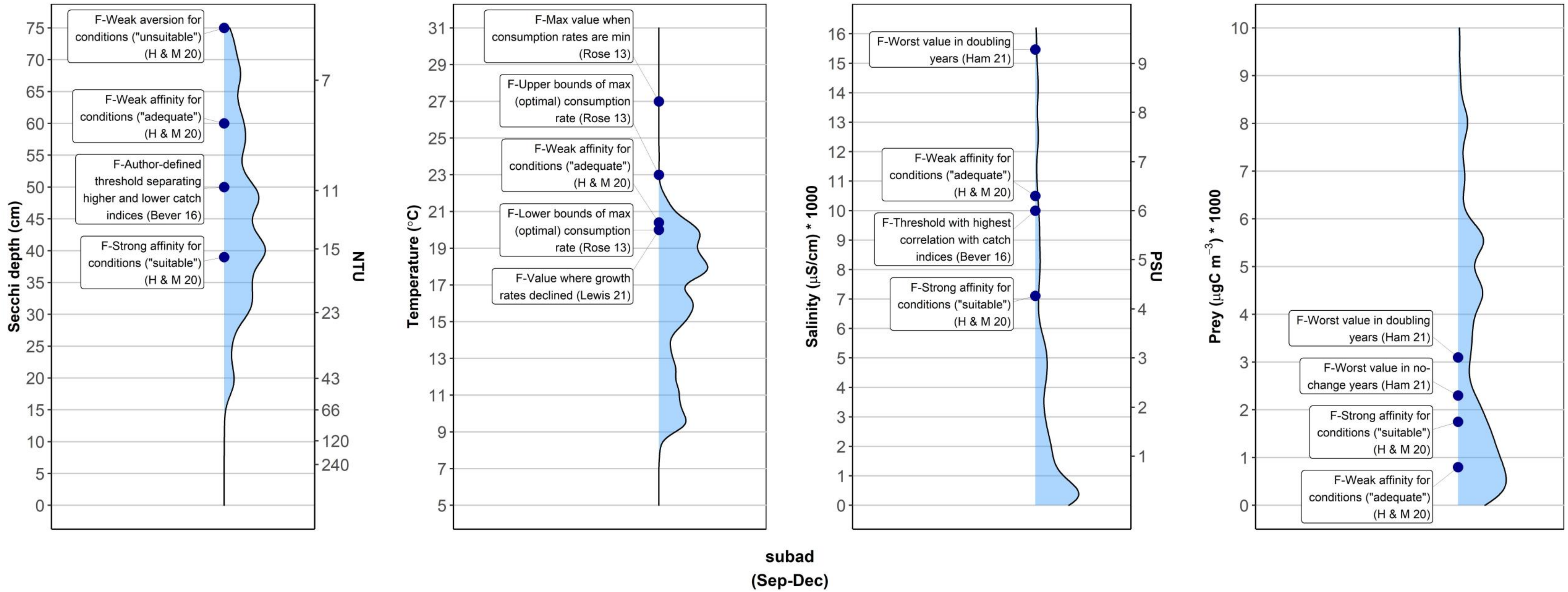

Figure 4e. Threshold Figure for subadults (Sep-Dec). Values extracted from delta smelt habitat attribute studies or proposed by Scott Hamilton using his performance and affinity analyses (blue dots). Study labels identify if the study was based on field (F) or lab (L) data, include brief value descriptions, and abbreviate the study author and year (full references can be found in Table 2). Distribution of delta smelt catch across the habitat attribute value range from field data collected between 1987 and 2014 (shaded blue area). Note that Secchi depth was converted to NTU using values from the Utah State University Extension; for the salinity panels in each figure, 10000 μS/cm = 6 psu (or ppt) following Sommer & Meija (2013) and Wagner et al. (2006).