Incorporating expanded sampling into an alternative abundance index for the Fall Midwater Trawl survey

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FULL RESEARCH ARTICLE

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Abstract

The Fall Midwater Trawl (FMWT) Survey has been conducted near continuously since 1967 to assess the abundance and distribution of pelagic fish species throughout the San Francisco Bay/Sacramento-San Joaquin estuary (Bay Delta). For most of this period, sampling 100 core stations provided data for abundance and distribution analyses. Another 22 (non-core) stations were added to the FMWT 8 to 28 years ago to supplement the original 100 (core) stations. However, relative abundance indices are published annually from only the data collected at the core stations. Here we incorporate data from non-core stations along with core station data to calculate an alternative index that also integrates modern estimates of water volume within the Bay Delta into an index calculation. The use of data from non-core stations in calculating the alternative index was particularly useful for American Shad (*Alosa sapidissima*) and Threadfin Shad (*Dorosoma petenense*). Consistently high catches at non-core stations for a couple species and modest catches for a couple additional species highlight the value of these additional catch data for our understanding of how fishes are distributed in the estuary.

Key words: abundance index, American Shad, California, Delta Smelt, Fall Midwater Trawl, Longfin Smelt, Striped Bass, Threadfin Shad

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Introduction

In 1967, the Fall Midwater Trawl (FMWT) Survey was initiated by the California Department of Fish and Wildlife (CDFW) to determine the relative abundance and distribution of age-0 Striped Bass (*Morone saxatilis*) in the San Francisco Estuary (Stevens and Miller 1983). FMWT sampling has been conducted annually from September through December since the project's inception, with the exceptions of 1974 and 1979. Although the original focus of the survey was to provide a measure of fall recruitment for young-of-year Striped Bass to inform impacts of state and federal water projects and help manage its sport fishery, the survey also provides information on the abundance and distribution of several pelagic fishes, including the endangered Delta Smelt (*Hypomesus transpacificus*), threatened Longfin Smelt (*Spirinchus thaleichthys*), American Shad (*Alosa sapidissima*), and Threadfin Shad (*Dorosoma petenense*) (Moyle et al. 1992; Rosenfield and Baxter 2007; Feyrer et al. 2009). The Smelt species are included in reporting because of their documented dramatic decline during the history of the survey and they have state or federal listed status. The Shad species are included because they are ubiquitous endemic species which are considered good indicator species due to their similar life histories to many other fish species in the estuary.

The FMWT annual indices are a summarizing value representing the relative population abundance of a fish species and useful for documenting relative estuary-wide abundance changes over time. The indices are calculated by multiplying the mean catch of each region by the regional water volume (i.e., weighting factors) and summing those products (for more detail, see Methods). They can be calculated from any species caught but are typically only reported for the fish species listed earlier. The indices have been reported annually since the start of the survey in 1967 and have been historically reported instead of CPUE (catch-per-unit-effort) because prior to 1985, CDFW did not use flow meters that would allow calculation of volume of water sampled.

Over time, the FMWT dataset has contributed a baseline for tracking and understanding of relative abundance and distribution trends for pelagic fishes (specifically those ≤ 15 cm fork length) in the San Francisco Estuary. Long term studies like the FMWT are important in documenting environmental and biological change, and can help researchers and managers understand changing regulation and functioning of ecological communities, allowing researchers to link biological patterns to environmental variability, and informing of human influences on ecosystems (McGowan 1990; Cody and Smallwood 1996; Ducklow et al. 2009; Clutton-Brock and Sheldon 2010; Magurran et al. 2010; Nelson et al. 2011; Likens 2012; Lindenmayer et al. 2012; Hofmann et al. 2013; Hughes et al. 2017). For example, FMWT data has helped highlight a dramatic estuary-wide decline in pelagic fish populations (Sommer et al. 2007; Baxter et al. 2010; MacNally et al. 2010; Thomson et al. 2010; Tempel et al. 2021) and enabled investigations of potential causes (MacNally et al. 2010; Thomson et al. 2010). The data have also shown the resilience of fish communities to long term drought cycles in the estuary (Mahardja et al. 2021). FMWT data have also been used to describe physical habitat characteristics of pelagic fishes (Feyrer et al. 2007; Feyrer et al. 2011), linking salinity distribution and fish abundance (MacWilliams et al. 2016), assessing Delta Smelt distribution with hydrodynamic complexity (Bever et al. 2016), and distributional changes of fishes to infer habitat use and migration (Rosenfield and Baxter 2007; Sommer et al. 2011; Polansky et al. 2018). FMWT abundance indices and sampling data have been used to support fish species listings under federal and state Endangered Species Acts (USFWS 2008a; CDFG 2009a) and have been referenced in federal Biological Opinions (USFWS 2008b) and used in state Incidental Take Permits (CDFG 2009b; USFWS 2019) to calculate allowable take (loss) limits for Threatened and Endangered fishes for water export operations in the southern Sacramento-San Joaquin Delta. This broad array of literature and management documents reflects the value of consistent, continuous monitoring. Nonetheless, some modification is typically necessary over time due to evolving management needs or financial constraints. This effort recognizes the need to update management practices and procedures in the face of improved methods, increased computing power, and new information (Reynolds et al. 2016).

The importance of FMWT data to the management of Delta Smelt led to several expansions of sampling panel over time to better understand the spatial distribution of the species. The new, “non-core” (i.e., not part of historical abundance calculations) fixed-location stations were added to the sampling panel in 1990–1991 and in 2009–2010 (**Fig. 1**), but their data has yet to be incorporated into abundance calculations and compared to historical abundance trends. Total catch and CPUE data from these non-core stations have been regularly reported (e.g., **https://www.dfg.ca.gov/delta/data/fmwt/Catch_Map.asp**; **https://nrm.dfg.ca.gov/documents/ContextDocs.aspx?cat=R3-FallMidwaterTrawl**).

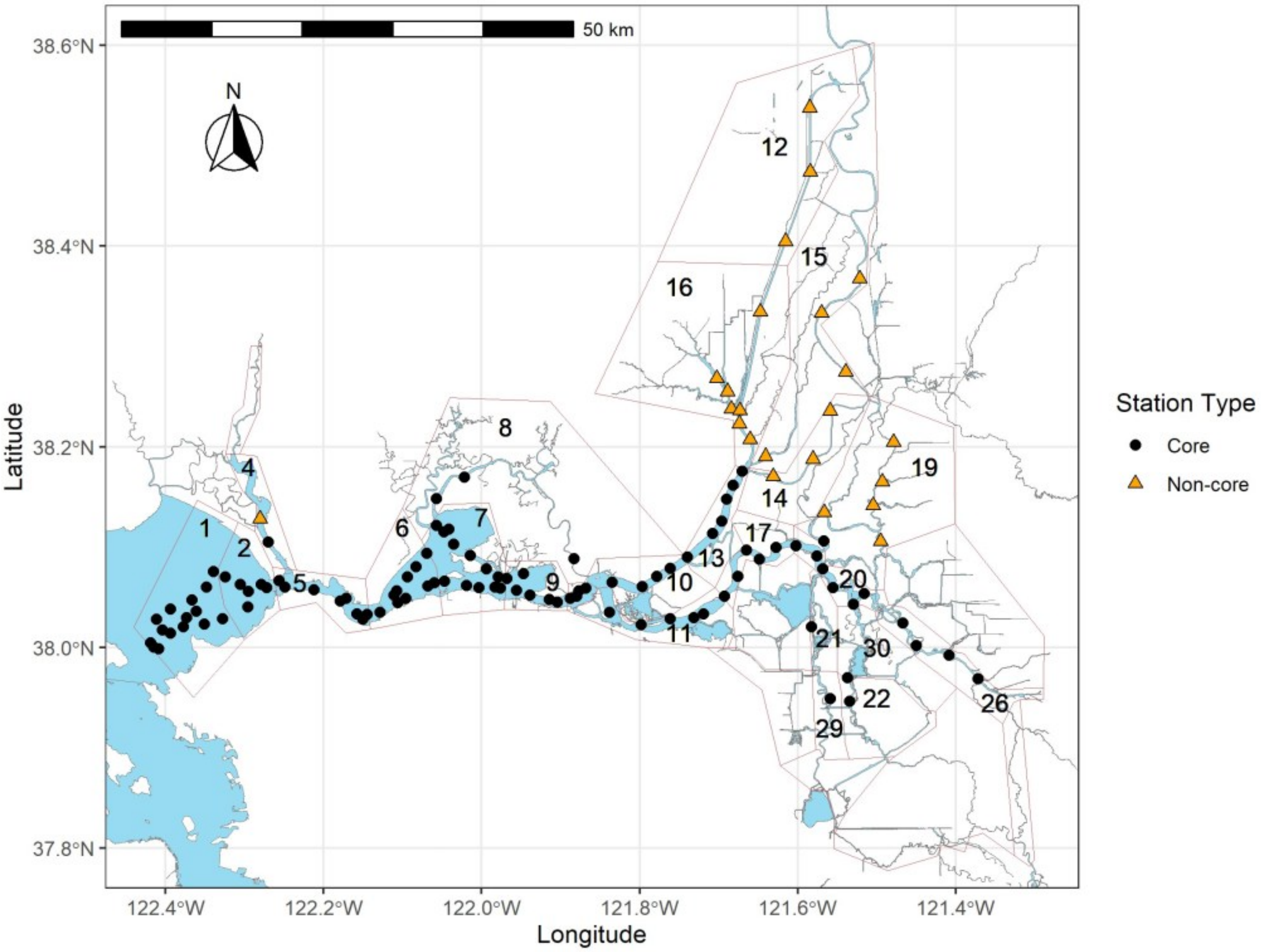

Figure 1. Map of all the core and non-core stations sampled during the Fall Midwater Trawl Survey. Core stations are the original 100 stations (circle symbols) used since the survey inception in 1967. Twenty-two non-core stations were added to the survey beginning in 1990 (triangle symbols). Polygons depict the 23 revised regions of the San Francisco Estuary and Sacramento-San Joaquin Delta. Water volume estimated for each region is used as a weighting factor in the calculation of the Alternative index (**Table 1**).

The goals of our study were to: (1) describe current abundance index calculation as a basis for comparing modifications; (2) describe recent bathymetry information, including developing regional strata, and methods for updating abundance index calculation to allow inclusion of stations added in the 1990s and 2000s; (3) describe the benefits of using added stations and regions for interpreting abundance trends of several key pelagic fishes.

Methods

We use the term “core station” to denote a sampling station whose fish catch data contributed to historical calculations of monthly and annual abundance indices, and “non-core stations” for those whose data did not originally contribute to index calculation. The core stations were grouped into 14 regions for index calculations. For each region, we calculated a regional weighting factor based on the estimate regional volume (acre-ft) by the California Department of Water Resources over 50 years ago (**Appendix 1 (PDF)**; Stevens and Miller 1983). The original sampling panel did not include regions and weighting factors encompassing new non-core stations added in 1990–91 and 2009–10, so no abundance calculation was possible incorporating these non-core stations until new regions were delimited and regional volumes estimated (i.e., weighting factors). Calculation of this “alternative index” using updated regional boundaries, new station groupings and updated regional volume estimates is discussed below.

For calculation of original abundance indices, not all stations sampled in 1967 or 1968 were core stations and not all core stations (and regions) were sampled throughout the entire duration of the FMWT (**Appendix 2 (PDF)**):

1. Stations initially sampled in 1967 or 1968 in south and central San Francisco Bays were discontinued after 1973 and were not considered part of the core station panel.
2. Prior to the 1970 sampling season and in response to improved knowledge of the distribution of age-0 Striped Bass, the original apportionment of 1 station per 100,000 acre-ft of water downstream of Martinez (stations ≤ 408; i.e., in Carquinez Strait, Napa River and San Pablo Bay) was modified to 1 station per 20,000 acre-ft, increasing the sampling panel in those downstream regions; for stations >408, station density was established at 1 station per 10,000 acre-ft.
3. For index calculation, neighboring core stations were originally grouped together into 17 regions, but after 1973 sampling was discontinued at stations in three regions (2, 6 and 9; in San Pablo Bay) except in a few wet years. Nonetheless, after 1973, regions 2,6 and 9 were no longer used for index calculation, leaving the remaining 14 regions for index calculation for the entire period of record.

FMWT deployment was monitored with flow meters first in 1978 and deemed to be sufficiently consistent that flow meters were not used to track variation in distance towed among stations (this negated estimating volume filtered for each tow as well). However, flow meters have been consistently used since 1985 to enable calculation of volumetric CPUE.

We calculated the original annual FMWT index (equation 1) as the sum of the four monthly (Sept–Dec) indices for each species of interest. The original monthly indices are calculated by multiplying the mean monthly (denoted *m*) species-specific (and for Striped Bass, age-specific) catch per tow (denoted *c*) for all core stations within each of the 14 regions (denoted *i*) by the region’s weighting factor (denoted *w*; in acre-ft x 104; **Appendix 1 (PDF)**). We then summed these products for all 14 regions to obtain a monthly index.

(1)

The alternative index is calculated similarly to the original index calculation; however, we used recently developed regional boundaries (and regional volume estimates), and these new regional boundaries did not match the original regional boundaries, so station groupings per region differed as did regional weighting factors for original and alternative index calculations. The new regional boundaries and the resulting weighting factors (regional water volumes) were derived from recently updated GIS and bathymetry measures encompassing all non-core station locations and virtually all core stations: some core stations in western San Pablo Bay (stations 305, 306, 307, 308, 308, 314) are not located within the updated regional boundaries but were assigned to region 1, the far western region, for abundance index calculation purposes. The lack of an additional region encompassing the afore listed stations (and its volumetric weighting factor) slightly lowers the magnitude of the calculated alternate annual index for fishes using the western portion of San Pablo Bay as habitat. Nonetheless, any catches at the stations will contribute to alternate index calculation through inclusion with catch values from stations in region 1.

These updated regional boundaries and water volume values are GIS-derived from an updated regional map (Fig. 1) created 12 June 2012 by John Donovan and Bernie McNamara at United States Geological Survey (USGS) with guidance from Pete Smith (USGS). As mentioned previously, these new regions are geographically different and more numerous than those used to group stations for calculation of the original index (23 new vs. 14 original regions, respectively). Stratification of the sampling locations into smaller geographic regions has the added benefit of lessening selection bias due to nonrandom-selection of sampling locations (Polansky et al. 2019). The alternative index weighting factors (regional water volumes) denote the hectare-meters of water in each specific region (Table 1). The assumed water surface elevation for water volume calculations for all regions was 1.25 m above the datum of NAVD88. Regional water volume calculations were done using GrBathCalc software based on the 2012 version of California Department of Water Resources Bay-Delta Office 10-m bathymetry grid (see Fregoso et al. 2017). We made volume calculations using the total water depth at each region.

Table 1. Regional surface areas, mean depths, volumes, and current weighting factors (ha-m) for regions (as defined in Fig. 1) used to calculate alternative abundance indices for fishes collected by the Fall Midwater Trawl Survey in the upper San Francisco Estuary, 1990–2021. Note: stations in bold are non-core stations.

Region ID	Region	Stations included	Area (km^2)	Depth (m)	Volume(km^3, total depth)	Weighting Factor (ha-m)
1	Mid San Pablo Bay	305, 306, 307, 308, 309, 310, 311, 314, 315, 321, 322, 323, 328, 334	93.9	4.4	0.410281	41028.1
2	East San Pablo Bay	325, 326, 327, 329, 335, 336, 337	39.4	4.6	0.180634	18063.4
4	Lower Napa River	340, **341**	15.3	2.7	0.040907	4090.7
5	Carquinez Strait	338, 339, 401, 403, 404, 405, 406	18.5	12.4	0.228146	22814.6
6	West Suisun Bay	407, 408, 409, 410, 411, 412, 414, 415, 416, 417	28.1	6.9	0.192913	19291.3

Region ID	Region	Stations included	Area (km^2)	Depth (m)	Volume(km^3, total depth)	Weighting Factor (ha-m)
7	Mid Suisun Bay	413, 418, 501, 502, 503, 504, 515, 516, 517, 601, 602, 603, 604	54.3	4.1	0.223497	22349.7
8	Suisun Marsh	605, 606, 608	12.3	4.2	0.051230	5123.0
9	Honker Bay	505, 507, 508, 509, 518, 519	20.7	5.9	0.122867	12286.7
10	Lower Sacramento River	510, 511, 512, 513, 701, 703, 704, 705	26.8	6.1	0.162162	16216.2
11	Lower San Joaquin Sacramento River	802, 804, 806, 807, 808	27.5	5.7	0.157291	15729.1
12	Deepwater Ship Channel (DWSC)	**795, 796, 797**	5.3	6.5	0.034695	3469.5
13	Sacramento River near Rio Vista	706, 707, 708, 709, 710, 711	13.0	6.7	0.086424	8642.4
14	Sacramento River near Ryde	**72, 717, 724**	4.2	4.6	0.019110	1911.0
15	Upper Sacramento River	**73, 712, 735, 736**	12.3	4.8	0.059642	5964.2
16	Cache Slough & Liberty Island	**713, 715, 716, 719, 721, 723**	22.7	3.8	0.086012	8601.2
17	San Joaquin River near Twitchell Island	809, 810, 811, 812, 813	9.0	8.8	0.079537	7953.7
19	North & South Forks Mokelumne River	903, **919, 920, 921, 922, 923**	12.6	4.6	0.057625	5762.5
20	San Joaquin River at Prisoners Pt	814, 815, 904, 905, 906	13.2	6.5	0.085761	8576.1
21	Holland Cut	902	6.6	4.8	0.031917	3191.7
22	Middle River	914	3.2	4.1	0.012958	1295.8
26	San Joaquin River near Stockton	909, 910, 911, 912	5.6	6.0	0.033369	3336.9

Region ID	Region	Stations included	Area (km^2)	Depth (m)	Volume(km^3, total depth)	Weighting Factor (ha-m)
29	Old River	915	3.5	4.2	0.015039	1503.9
30	Mildred Island	908, 913	10.6	5.2	0.055070	5507.0

To calculate the monthly FMWT alternative index, we multiplied the mean monthly catch per tow (denoted *c*) for all stations within each of the 23 regions (denoted *i*) by the region's weighting factor (denoted *w*; in ha-m). These products were summed for the 23 regions to obtain a monthly index. Each month's index was rounded to the nearest whole number and the four monthly (denoted *m*; Sept–Dec) indices were summed to create the annual index (equation 2). This process was repeated for each species of interest (Age-0 Striped Bass, Delta Smelt, Longfin Smelt, American Shad, and Threadfin Shad). Striped Bass was chosen because its management was the original impetus for the survey, the Smelts were selected because they are endangered and therefore of management interest, and the Shads were selected because they were historically ubiquitous within the estuary since their introductions and possess differing life histories: resident (e.g., Delta Smelt, Threadfin Shad) and anadromous (e.g., Striped Bass, Longfin Smelt, American Shad).

(2)

As an additional assessment of usefulness of non-core stations, we first calculated a volumetric CPUE (catch per 10,000 m^3 of water sampled) for each species and tow (see **CPUE protocol document**). From there, we calculated a mean CPUE for each grouping of year, species, and station type (core or non-core). To determine if there was an increase in mean CPUE from the addition of CPUE values from non-core stations (100 core stations vs. 116–122 when non-core stations are included) for each fish species, we conducted a non-parametric sign test (Conover 1999) with continuity correction because CPUE data violated assumptions of normality, the distribution of CPUE was asymmetrical, and possessed numerous outliers. This analysis was done in R 4.2.0 (R Core Team 2022) using the package 'BSDA' (Arnholt and Evans 2017).

Results

Non-core stations provided valuable additions to the relative abundance indices for various species and years. For Delta Smelt between 1999 and 2004, the non-core stations (primarily five stations in Cache Slough) represented a 5–258% higher index value compared to just the core stations (**Fig. 2**). After 2004, non-core stations contributed less frequently and generally less in magnitude to alternative index values (**Fig. 2**). The contributions of non-core stations to Longfin Smelt indices were typically negligible compared to contributions of core stations.

Figure 2. Plot showing Alternative index including all (100 core and 22 non-core) stations (circle symbols), only core stations (triangle symbols), and the Original index with core stations (square symbols) for key pelagic species from Fall Midwater Trawl Survey, 1990–2021. Species include Delta

smelt (*Hypomesus transpacificus*), Longfin smelt (*Spirinchus thaleichthys*), American shad (*Alosa sapidissima*), Threadfin shad (*Dorosoma petenense*), and age-0 Striped Bass (*Morone saxatilis*). Vertical lines denote when additional non-core stations were added in 1991 (from 4 to 16 stations), 2009 (from 16 to 21 stations), and 2010 (from 21 to 22 stations).

Contributions of non-core stations to indices for American Shad were relatively high, typically 30–60% higher than only indices from core stations but as high as 261% during 2004 (**Fig. 2**). These high contributions occurred most frequently from 1990–2012. Similarly, the contributions of non-core stations to Threadfin Shad indices were often high, adding 3–3536% to the index over 1990–2021 (**Fig. 2**). Since their addition to the survey in 2009, DWSC stations contributed the vast majority of Threadfin Shad catch to the annual index through 2021 (**Fig. 2**). Non-core stations typically contributed a negligible amount (≤ 20%) to the annual abundance index of age-0 Striped Bass, except in 2014, when stations in Cache Slough contributed an additional 89% (**Fig. 2**).

Alternative index values were typically higher than the original index values for all species, primarily due to the addition of stations and regions (if occupied) to the index calculation. Other factors contributing to the increases include different regional boundaries (creating different station groupings), and revised bathymetry resulting in new regional water volumes. However, the alternative and original indices showed similar populations trends over time due to the same raw catch values for core stations used in calculation of indices.

The sign test showed American Shad median CPUE was 45% greater with the added non-core stations included (labeled all stations) compared with only core stations and this difference was statistically significant. None of the other species examined showed a similar significant increase, although Threadfin Shad is trending towards this pattern and likely to be significant with additional years of sampling.

Discussion

Here, we conduct the first formal evaluation of pelagic fish use of a panel of FMWT sampling stations identified as “non-core” and added to improve our understanding of Delta Smelt use of the estuary. We also take advantage of updated upper SFE bathymetry and revised regional boundaries to incorporate these long-sampled, non-core stations (n = 22) added to the FMWT survey panel and their data into abundance index calculations for commonly collected pelagic fishes.

What is known about the life histories of these fish helps explain some of the observed distribution patterns. Delta Smelt and Longfin Smelt rarely occupy the south and eastern Delta in summer because of high water temperatures (Nobriga et al. 2008; CDFG 2009a; Jeffries et al. 2016). Likewise, they are typically not captured in areas in the Sacramento River above Isleton, except when migrating prior to spawning in the late Spring (Moyle 2002; Sommer et al. 2011). For the Sacramento River, eastern Delta, and southern Delta, both smelt species migrate to these areas from late December through Spring (Wang 1986; Rosenfield and Baxter 2007a; Sommer et al. 2011), mostly outside the FMWT sampling period. During migration, capture of these species by the FMWT net (which primarily samples open water) may be reduced as they appear to take advantage of upstream currents and “surf” the flood tides upriver and then move to the shoals (or close to the bottom) during ebb tides (Bennett and Burau 2015), thus may only be vulnerable to the gear during a portion of the tidal cycle. For Longfin Smelt, the new non-core stations in Cache Slough and the Sacramento Deepwater Ship Channel were mostly upstream of known suitable habitat during fall (Baxter 1999). For Delta Smelt, these new north Delta non-core stations overlapped with recently recognized rearing habitat in Cache Slough and the Sacramento Deepwater Ship Channel (Baxter et al. 2010; Sommer and Mejia 2013; Bush 2017; Hobbs et al. 2019) and thus more regularly provided Delta Smelt catches prior to the Pelagic Organism Decline in the early 2000s; however, in the past 15 years Delta Smelt have become increasingly rare throughout the estuary, including at the more recently added non-core stations.

Threadfin Shad is a temperature and salinity tolerant resident that resides year-round and finds habitat throughout the estuary (Feyrer et al. 2007), but is most commonly found in slow moving, fresh to oligohaline water (Wang 1986; Feyrer et al. 2009). The declines that have been observed in the eastern and southeastern Delta are most concerning, but Cache Slough and the DWSC appear to be a refugia of sorts for this species.

American Shad spawns in upstream tributaries in spring and early summer and juveniles disperse downstream and throughout the Delta and estuary from late summer through winter to grow larger before migrating to the ocean (Moyle 2002). As overall abundance has declined, so too has apparent distribution (e.g., reduced densities in Sacramento River above Isleton in the eastern Delta). Overall abundance of juvenile American Shad in the fall appears related to spring outflow during the spawning season (Jassby et al. 1995; Thomson et al. 2010) and declining abundance appears to be mirrored in diminished distribution.

Similarly, Striped Bass is an anadromous species which migrates inland to spawn in the late spring and early summer (Dill and Cordone 1997), the timing of which is likely dictated by Delta outflow and water temperature (Goertler et al. 2021). Striped Bass eggs and larvae must remain pelagic, suspended by turbulence, to survive until hatching. Thus, these early life stages are transported by net river currents and dispersed by the tides, and similar to American Shad, their habitat in the Delta and upper estuary is broad by fall (Feyrer et al. 2007). However, the decline in Striped Bass abundance has been going on since at least the 1980s (Sommer et al. 2011).

The alternative indices show the expanded sampling effort has been particularly useful for Threadfin Shad; the majority of our annual catch of this species comes from non-core stations in the DWSC since those stations were added in 2009. As habitat suitability and abundances have declined elsewhere in the estuary, the DWSC has become a refuge for some species.

Overall, the annual abundance indices and core vs all stations comparison (sign test) indicated the additional stations were most used by American Shad (**Fig. 2**, **Table 2**). Threadfin Shad and Delta Smelt non-core catches are more variable and thus these additional stations were not significant yet still informative in regard to understanding the full range of these species. The non-core station catches of Longfin Smelt and Striped Bass were generally too low to contribute much to abundance calculations. While the sign test and indices do not support a need for the non-core sampling effort for all species (e.g., Longfin Smelt), we argue the additional stations expand into the full true range of these species examined. This is important to sample over long time periods to capture regional distribution shifts that may occur in the future. Further, periodic unusually high catches in specific years (e.g., Delta Smelt index in 2004) and the addition of some catch data in years which would otherwise be considered historically low (e.g., Threadfin Shad indices from 2009–2021) make the additional sampling effort a worthwhile endeavor. Because water managers determine take levels of endangered species based on FMWT annual catch data, high catch years at non-core stations have considerable value in making informed management decisions.

Table 2. Sign test results comparing mean CPUE values between only core stations (n = 100) and all stations (n = 116–122) from 1990–2021 Fall Midwater Trawl catch data. *Represents number of years in which mean CPUE increased due to catch from non-core stations out of the past 32 years.

Species	Median CPUE Core stations	Median CPUE all stations	Years non-core increase*	Z-statistic	P-value
Delta Smelt	0.25	0.28	6	2.83	0.99
Longfin Smelt	0.57	0.46	0	5.48	1
American Shad	3.78	5.47	29	4.42	**<0.001**
Threadfin Shad	6.84	6.84	19	0.88	0.19
Striped Bass age-0	0.92	0.82	2	4.77	1

Clearly there is value in maintaining consistent long-term datasets while updating methods and analyses with the changing needs of adaptive management of the estuary. Abundance indices such as these are useful for understanding variation in relative abundance trends over time and for comparison purposes with model- or design-based estimates (Newman 2008). These types of models more directly estimate population abundance and standard error (vs. relative abundance) for specific fish species adjusted for gear and life history parameters. The comparisons between indices and models are useful for understanding the assumptions and bias of each method. We also chose to produce a relative abundance index over other approaches such as model- or design-based estimates because it is calculated using the same method as the original FMWT indices, which have been reported for decades and are familiar to researchers and managers. The intention is not for this new index to replace the original index, but rather to incorporate non-core stations into an index and provide an additional tool for water managers. Future efforts should examine the value of expanded sampling or alternative analysis of fish populations. However, when leveraging the FMWT dataset towards other uses, one needs to thoroughly understand the limitations of the fishing gear such as size and species bias (Mitchell et al. 2019; Mitchell and Baxter 2021; Huntsman et al. 2022) and also recognize that FMWT is a general pelagic fish survey that is not designed to specifically target any one particular species such as Delta Smelt or Striped Bass.

In conclusion, the alternative indices presented here serve to both update our index calculation approach and make use of the data from expanded sampling effort over time. Catch data collected from the 22 non-core stations from the past 8–32 years provided a valuable insight regarding regional habitat use and abundance changes for our pelagic fishes. As data collection continues, future studies should integrate these catch data into their analysis.

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