Landscape Change in Suisun Marsh

By

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Abstract

Suisun Marsh is a 470 km^2 wetland situated between the Sacramento-San Joaquin Delta and San Pablo Bay in the San Francisco Estuary. Today, about 80 percent of the marsh plain is privately owned by duck hunting clubs and managed in accordance with conservation agreements. A complex network of sloughs weaves through the Marsh, providing habitat for numerous aquatic species. Together the waterways and marsh plain support a stunning array of species, provide exurban open space, and are increasingly called upon to meet regional conservation objectives. The Marsh is vulnerable to sea level rise impacts, pollution, and other human impacts, so understanding how it functions so it can be successfully managed to meet the lofty objectives set out for it will be critically important in the decades ahead. This study reviews landscape-scale historical ecology of Suisun Marsh and examines recent variation in fish populations from a geographical perspective.

Chapter 1 presents the geomorphic and physical history of the landscape, explaining processes driving wetland development and contributing to unique functional subregions within the Marsh. Chapter 2 examines human- and animal-landscape interactions. Ecologically

significant shifts in human and animal populations during the Spanish and Mexican eras, followed by agricultural development in the late 1800s and duck club management starting around 1900, have kept the Marsh landscape continually changing. The rate and magnitude of landscape change has intensified since European contact in 1769 and even more since the Gold Rush of 1849. Chapter 3 explores landscape-scale variation in species distribution and abundance based on a long-term study of Suisun Marsh fishes and invertebrates and presents these data in novel animations. Animated maps are used to explore shifting populations of fishes and invertebrates from 1980 to 2013, demonstrating the value of long-term biogeographical datasets in understanding biological communities at the landscape scale.

Understanding both the deep and recent history of the Marsh provides insights and inspiration, informs management approaches, points to potential restoration and rehabilitation targets, and affects attitudes about appropriate human interactions with this dynamic biological system and landscape.

Acknowledgements

My heartfelt thanks go out to my committee members who offered consistent, firm, and ever-wise advice. I am fortunate to have benefitted from the technical expertise of professors Peter Moyle, Deborah Elliott-Fisk, and Jay Lund throughout this project. Their scientific conscientiousness is well balanced by their spirited love of life and learning.

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Turning up the right historical documents can be a challenge, and cogent advice from Alison Whipple, Chuck Striplen and Robin Grossinger of the San Francisco Estuary Institute was a great help. Fellow geographer Joseph Honton's historical ecology research in the Laguna de Santa Rosa watershed provided a helpful research template for me to follow, but moreover his meticulous and deeply thoughtful approach to the work itself is a lesson that I will always carry with me.

When I first heard tell of the dataset associated with the Suisun Marsh Fish and Invertebrate Study I immediately wanted to animate it, but I had little sense of how to go about it. My cousin Tony MacCabe graciously dedicated time and energy to solving my database management problems, even from the other side of the continent. William Fleenor always seemed to point me in the direction of progress when I thought I had reached a wall, particularly when he introduced me to Steven Micko at just the right moment to assist with approximating the effects of the Suisun Marsh Salinity Control Gates on flow and salinity.

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Chapter 1

Physical Processes Shaping Suisun Marsh

Introduction

Suisun Marsh, a wetland located between San Pablo Bay and the Sacramento-San Joaquin Delta in California (figure 1.1), is a place of constant and relatively rapid change, with vital connections to regional ecological processes. Natural forces, such as faulting, winds, tides and river flows have sculpted this wetland landscape over the past 6,000 years. Telltale signs of geomorphic processes are now largely obscured by human modifications; nevertheless, by comparing maps made at different times, drivers of change can be seen in the patterns that emerge, helping to infer processes. Novelties and subtleties of landscape ecology are often found in historic accounts, and tracking landscape change through time can aid both likely current and future management practices. High-energy drivers such as tides, great rivers, and winds have sustained constant and relatively rapid geomorphic and ecological change throughout the 6,000-year history of the Marsh.

Geology, tectonics, and geomorphology

About 25 mya[1], the Pacific Plate met the North American Plate and began to slide north-northwestward. Ten million years later, this transformational boundary reached the area that would become the San Francisco Estuary. By 3.5 mya, contact between plates changed from

[1] Mya = million years ago.

Figure 1.1. Location of Suisun Marsh in relation to San Pablo Bay and the Sacramento-San Joaquin Delta (CalAtlas 2012). Non-tidal wetland areas shown in pale green; tidal wetlands shown in dark green (SFEI 2012).

plates sliding past one another to plates sliding at an angle relative to one another, a combination of sliding and compression termed “transpression.” The resulting increase in friction initiated the rise of the Sierra Nevada. About two million years later, these same forces began to lift the Coast Ranges that frame the San Francisco Estuary we know today. The Coast Ranges on the North American Plate were pulled and stretched by the Pacific Plate in a north-northwesterly direction relative to the Central Valley, a process that continues today. Although all of the Coast Ranges move in the same general direction, westward segments move relatively faster than eastward ones. Thus the San Francisco Estuary landscape has been, and continues to be, rapidly reconfigured – at least in geologic time (Sloan 2006).

The estuary is geologically young, having changed dramatically over the past one million years. The Central Valley of one mya was a large inland lake and what is now the floor of San Francisco Bay was a plain crossed by small rivers. Around 620,000 years ago, this configuration shifted. The inland lake began draining to the Pacific by down-cutting the present Sacramento River channel that passes by Suisun Marsh and then flowing through Carquinez Strait and into San Francisco Bay. Much later, during the ice age about 20,000 ybp, sea level was lower and the ocean shoreline was situated nearly 50 km (30 mi) west of the Golden Gate. At this time, California's greatest river meandered between floodplains that now lay beneath San Pablo and San Francisco bays (Sloan 2006).

The valley in which Suisun Marsh formed was created by tectonic activity along the Concord-Green Valley Fault System, as well as by smaller nearby faults. A series of northwest-southeast trending anticlines and synclines undulate to depths up to 2,500 meters beneath the peat soils and alluvium of the eastern Marsh and Grizzly, Suisun and Honker bays. These anticlines and synclines are underlain by southwest-dipping thrust faults (Unruh and Hector 2007). The Potrero Hills are comprised of Tertiary rocks uplifted by an anticline; the Montezuma Hills are made of younger alluvial deposits that also have been uplifted (Sloan 2006).

Approximately 10,000 years ago, sea level was still much lower than it is today. At this time, the Suisun Marsh region was a river valley. Sea level rose as glaciers melted in the Earth's warming climate and fringing marshes advanced upslope as the bays filled with water (Atwater *et al.* 1979). At times, the water rose so fast that areas of marsh failed to keep pace and were drowned, as seen in layering of marsh deposits and intertidal and subtidal sediments (Atwater *et al.* 1977). Around 6,000 years ago, the rate of sea level rise slowed dramatically, fostering the formation of extensive tule (*Schoenoplectus* spp., *Bolboschoenus* spp.) marshes in the eastern estuary, including Suisun Marsh (Atwater *et al.* 1979; Drexler *et al.* 2009; Malamud-Roam and Ingram 2004) . As rising waters filled the lower drainages of Suisun Valley Creek and its tributaries, tules grew and decayed, and sediment was deposited by rivers, tides and wind, forming thick layers of organic soils.

Climate variation in recent millennia

The Earth's climate has warmed slowly since the last ice age (Burroughs 2007). In the San Francisco Bay region, the change has not been a steady, gradual shift. Sediment cores and tree rings reveal wide fluctuations in climatic conditions occurring on time scales of a few years to decades. This erratic variation can be attributed to the climactic boundary zone in which the region is situated, with wetter, cooler conditions to the north and drier, hotter conditions to the south. At a given time, the weather may be moderate or more like that to either the north or south. Paleoclimate studies have revealed relatively recent extended droughts and deluges unlike any seen since Euro-American colonization of California. Compared to the past 2,000 years, the past 150 years have exhibited an anomalous pattern of very stable conditions (Malamud-Roam *et al.* 2007). The historic record demonstrates that unpredictable shifts and conditions less favorable than those to which we are accustomed are typical. Imminent effects of anthropogenic climate change further increase our uncertainty in the future climate of the San Francisco Bay region.

Process-driven subregions

Discussions of Suisun Marsh often refer to the “western” and “eastern” marsh, and numerous reports have carved the Marsh into alternate subregions to suit different purposes. For example, the *Suisun Marsh Habitat Management, Preservation, and Restoration Plan* (2011) divides the Marsh into four subregions for management purposes. Here we designate subregions according to physical drivers of landscape formation to understand processes contributing to the array, extent and proportion of habitat types within the Marsh.

The modifications that transformed hydrologic processes within Suisun Marsh did not begin until the late 1800s. Levees and dikes, hydrologic diversions and other such infrastructure came later to Suisun Marsh than to the Delta or to the urban edges of San Francisco Bay. Surveying and mapping marshes was a difficult task in the era before aerial photography; consequently, our map record contains considerable ambiguity. Yet maps made between 1875 and 1910 tell a compelling story about physical dynamics prior to settler’s alterations of wetland processes. Sufficient geomorphic features are represented to establish functional zones that likely existed and that still affect the landscape.

A careful look reveals at least four major and three peripheral process-driven subregions in the historic Marsh, with major subregions being those that cover large contiguous areas. Major subregions include the (1) western marsh, including Suisun and Goodyear sloughs and their tributaries; (2) southeastern Montezuma Slough distributary network; (3) northeastern

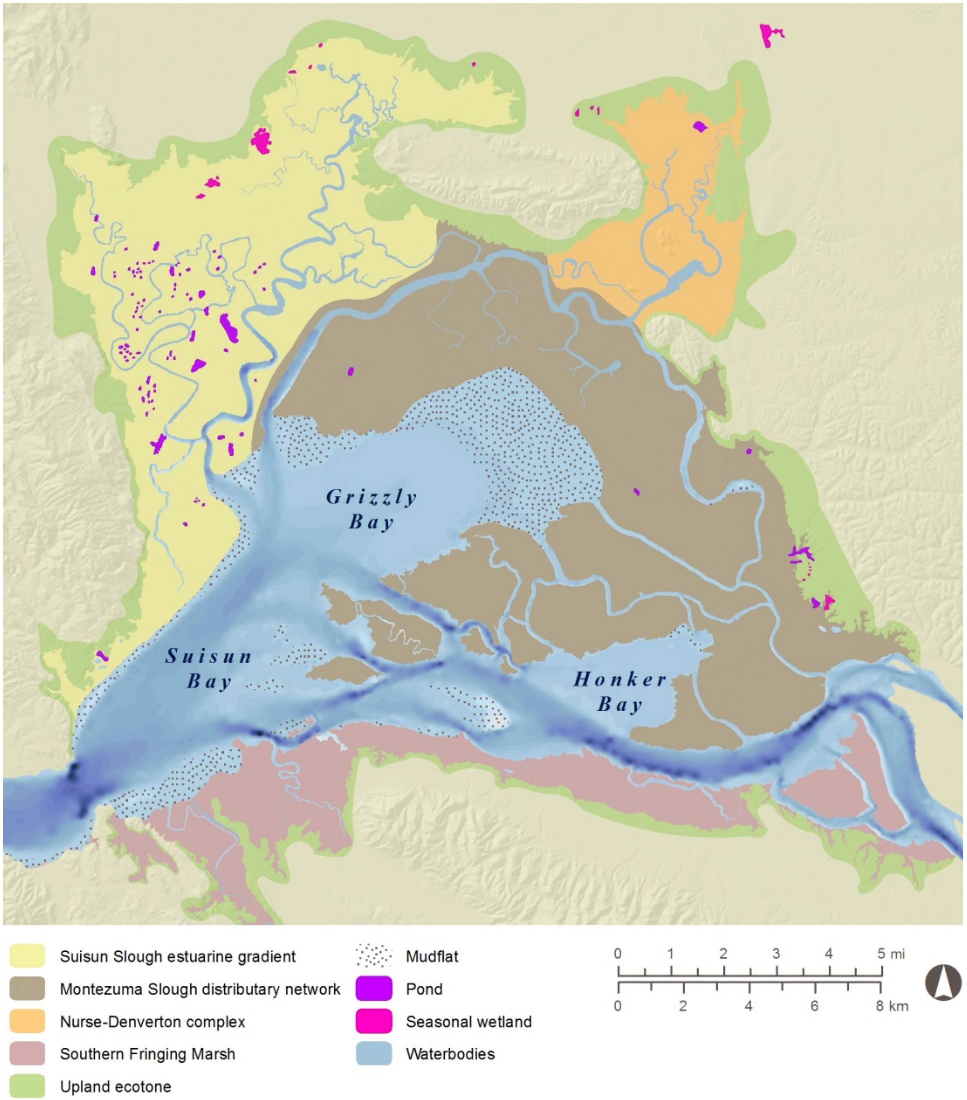

Figure 1.2. Historical functional subregions of Suisun Marsh, late 1800s. Sloughs, landforms, and bathymetry from US Coast Survey navigational chart with measurements taken 1856 - 1867 (Bache 1872), ponds and wetlands from topographic maps surveyed 1896 - 1907 (USGS 1896; USGS 1918-a; USGS 1918-b). Topography is contemporary (Gesch *et al.* 2002).

Nurse-Denverton Slough area and (4) southern fringing marsh. Peripheral subregions are associated with ecotones at marsh edges and include transitional landscape features covering smaller areas such as the (5) marsh-upland ecotone, (6) ephemeral wetlands near the marsh edge and (7) tidal mudflats (figure 1.2). In addition to the subregions outlined above, there are finer-scale subregions (e.g., marsh plain microtopography) as well as complex physical processes (e.g., slough hydrodynamics) with important ecological implications that are beyond the scope of this chapter. Upland ecosystems, though intrinsically linked to marsh processes, are likewise not evaluated herein.

The western marsh: Suisun Slough estuarine gradient

On the western side of Suisun Marsh, Suisun Slough and its tributaries follow a common pattern observed where freshwater creeks meet tidal bays. Freshwater streams give way to winding, tidally influenced waterways and the main geomorphic drivers are hydrologic throughout. Not including low-lying marsh, the Suisun Slough watershed covers approximately 486 km^2 (120,000 acres). The processes and ecology of this Marsh subregion might be compared to nearby creeks with similar watershed area and topographic relief, such as Sonoma Creek in Sonoma County. Suisun, Goodyear, Cordelia, and smaller sloughs drain Green Valley, the eastern flank of the Sulphur Springs Hills, and the western side of the Potrero Hills. Western marsh sloughs are highly sinuous compared to other sloughs in Suisun Marsh, suggesting they have been developing for a long time (Atwater *et al.* 1979; Hall 2004).

The boundary of the historic western marsh crosses Joice Island from Grizzly Bay to the Potrero Hills. The boundary is imprecise due to continuous fluctuations caused by tidal and fluvial variation affecting the direction of flow in Cutoff Slough, which connects Suisun Slough to Montezuma Slough at the northern end of Joice Island. The historic Suisun Slough had a straightforward estuarine gradient, with fresher conditions upstream where it is fed by Laurel and Ledgewood creeks to increasingly brackish conditions downstream, except when freshened at the downstream end by very high outflows from the Delta. The lower western marsh was the most tidally influenced and least river-influenced area within Suisun Marsh. Reconstructions of historic salinity provide evidence that Suisun Marsh's western subregion was generally the most saline part of the Marsh (Collins and Grossinger 2004), a condition driven by proximity to San Pablo Bay and distance from the Delta. Conditions varied widely from year to year, however, depending on Delta outflows.

Maps show that the historic western marsh featured numerous ponded water bodies scattered across the marsh plain among channels, a feature common to tidal marshes around San Francisco and San Pablo bays. These ponds primarily appear west of Suisun Slough between Wells and Cordelia sloughs. USGS topographic maps delineate 87 ponds in the marsh plain of western Suisun Marsh around the turn of the 20th century (USGS 1896; USGS 1918a; USGS 1918b; USGS 1918c). Other early maps indicate additional natural ponds near Cordelia Slough (Stoner 1934; Stoner 1937) and reaffirm that there were many ponds in this area (Arnold 1997), although pond numbers and locations represented in maps vary.

Ponds in the western marsh are an integral part of local duck hunting lore, and these natural features inspired environmental management decisions made throughout the 20th century. In 1900, only a few duck hunting clubs could be found in the Marsh, and hydrologic management was nascent, so ponded water features on maps drawn at this time were likely natural. They were clearly habitat for migrating flocks of waterfowl, as attested to by market hunters' stories in the mid-1800s, locations of the earliest hunting clubs, and the route of the railroad that serviced them (Arnold 1997).

Numerous geomorphic processes can lead to the formation of ponded areas in marshes. *Marsh pannes* form where water is hydrologically trapped and isolated on the marsh plain and is so deep and persistent or so saline due to evaporation that plants cannot colonize. *Ponds* on the marsh plain are connected at least occasionally to tidal flows and therefore are fresher than pannes. *Sag ponds* are formed by subsidence along faults and can occur in uplands or in marshes, and *salinas* are shallow, hydrologically isolated, periodically dry wetlands that form in the marsh-upland transition zone and precipitate salts (Collins and Grossinger 2004).

The Cordelia and Green Valley faults run north-south along the western edge of the western marsh region and may have been a factor contributing to pond formation. The Sulphur Springs Hills shelter the western marsh from prevailing winds to some extent, and this protection may have translated to slower marsh plain formation and thus better conditions for pond formation than in other parts of Suisun Marsh. Protection from winds may also have affected duck habitat preferences (Monda and Ratti 1988), especially in comparison to the windblown southeastern and northeastern subregions of Suisun Marsh (see following text).

Animals forage, trample, and puddle in wetlands, grazing on vegetation and excavating channels and ponds in the process (Mitsch and Gosselink 2007). Biogenic pond formation may have been driven by elk and other ungulates until their rapid decline in the 1850s, but this would not explain the skewed spatial distribution of ponds. Several early accounts credit the ducks themselves for pond formation in western Suisun Marsh. An early article by the renowned 20th century California botanist Willis Jepson mentions duck clubs that were presumably located in the western marsh because that was the only area with clubs at the time. Jepson (1905) described interactions between ducks and landscape processes as “[w]hen the [wild] geese are in great numbers they eat out the tule so effectively that ponds, often of considerable extent, are formed." He explained that the widespread and prolific fennel (sago) pondweed (*Stuckenia pectinata*) subsequently colonized ponded areas, which were three to four feet deep. "Before the ducks come the ponds are filled with regular masses of the fennel pondweed, as even in its growth as a field of young grain." He is likely referring to ponds at the Ibis Club, because it had ponds of this depth (Stoner 1937).

James Moffit (1938) also described sequential species-specific waterfowl feeding activities that formed and then deepened the ponds:

> Originally the Lesser Snow Geese (*Chen hyperborea hyperborea*) made the ponds on this marsh by tearing up clumps of three-square (*Scirpus americanus*) to secure its bulbs for food… Then, the Whistling Swans (*Cygnus columbianus*), working in the areas opened by the geese, deepened the ponds to three feet or more by tilting up like surface-feeding ducks and reaching down with their long necks. Plant growth, of which sago pondweed (*Potamogeton pectinatus*) is by far the most important one locally, becomes established when ponds with proper conditions of salinity and requisite depth (18 inches or more) are created. Sago pondweed, an excellent food plant, attracts surface-feeding ducks, notably Pintail (*Dafila acuta*), until the ponds are deepened so that the growth is no longer within reach of the surface-feeders. The ponds then become attractive to diving ducks, of which the Canvasback (*Nyroca valisineria*) is the only common one in this region. Canvasbacks in their feeding operations, may further deepen the ponds.

Annual precipitation totals during the late 1800s and early 1900s were frequently above average, so large Delta outflows kept all of Suisun Marsh unusually fresh during this time period. Saltier conditions may have contributed to pond formation in previous periods of extended drought; however, as sago pondweed thrives in brackish and fresh water and was reliably present, well-distributed and prolific in ponds in mid- to late summer when ducks stopped through on their migrations, pond water was not hypersaline at the driest time of year in the western marsh and thus persistent ponding was not due to hypersaline conditions. The historic role of waterfowl in pond creation and maintenance is still a bit of a mystery. Speculations on biogenic pond formation hinge on historic waterfowl abundance and use of ponds by waterfowl and other Marsh denizens.

The southeastern marsh: Montezuma Slough distributary network

Suisun Marsh is sometimes referred to as "the western Delta," and the southeastern portion of Suisun Marsh, bounded by the Montezuma Hills to the east and Montezuma Slough and adjacent marshes to the north, is the part of the Marsh that most lives up to the name. It is more similar to the Delta than to smaller estuarine systems around San Francisco Bay, with large freshwater inputs, webs of interconnected sloughs and numerous islands. Historically, few ponds were located here. Wind-influenced accretion and disturbance most likely were, and still are, major factors shaping this subregion.

The watershed that feeds the upstream end of Montezuma Slough at Van Sickle Island is that of the entire Sacramento-San Joaquin River system, which drains about 162,000 km^2 (40 million acres) or 40 percent of the state of California. After flows are pinched between the Montezuma Hills and the northern face of the Mount Diablo range, deltaic processes resume in the southeastern subregion of the Marsh as great rivers and tides intermingle. This geomorphic extension of the Delta is characterized by numerous islands (e.g., Chipps, Wheeler, Simmons, Grizzly, Ryer) dissected by open-ended sloughs (see figure 3.1). Island-building processes of sediment deposition are ongoing within the main river channel. Shoals form where water moves slowly and channels are regularly dredged to maintain passage for ships, necessary even though sediment inputs are currently limited by upstream dams. The southeastern Marsh was historically fresher, on average, than the western Marsh (SFEI 2012).

While sediment delivered by the Sacramento and San Joaquin rivers doubtless played an important role in formation of the entirety of Suisun Marsh, marsh-building sediment delivery has been greatest in the southeastern subregion in the recent past (see figure 2.2). Sediment delivery and deposition accelerated greatly due to the influx of sediment from hydraulic gold-mining operations in the late 1800s and early 1900s (USGS 1999, Chapter 2). A large quantity of this sediment settled out of the slow-moving, wind-affected shallow water at the northeastern end of Grizzly Bay. The bayward portion of Grizzly Island accreted so rapidly that vascular plants were not a major part of the soil-building process; thus soils are mineral (Soil Survey 2014), and this area is not at risk of subsidence through oxidation of peat as are other areas of the Marsh. Mercury used in gold-mining operations is likely present in these soils, a subject ripe for further study.

The near absence of ponds represented in the southeastern and northeastern marsh subregions by early USGS topographical maps is striking, with only seven illustrated in these subregions combined. In comparing the first USGS (1896) topographical surveys of the western marsh to the first surveys of the southeastern marsh (USGS 1918a; USGS 1918c) the latter maps are of overall better quality and almost no ponds appear in them. Absence of ponds in the southeastern marsh is affirmed in early Solano County Surveyor maps (Solano County Surveyor 1920s).

Hydrology dominates landscape processes in the southeastern subregion of Suisun Marsh, but the wind also makes its mark. The atmosphere above the Montezuma Hills is among the windiest in the state, with mean annual wind speeds of up to 8.5 m/s (19 mph) (AWS 2010). Embayments on Frost Slough, Little Honker Bay in the northeastern marsh and at the confluences of Nurse and Denverton sloughs (also in the northeastern marsh) all appear at the downwind terminus of stretches of water that align with prevailing winds (figure 1.3). Grizzly and Honker bay morphology also follows this directional pattern.

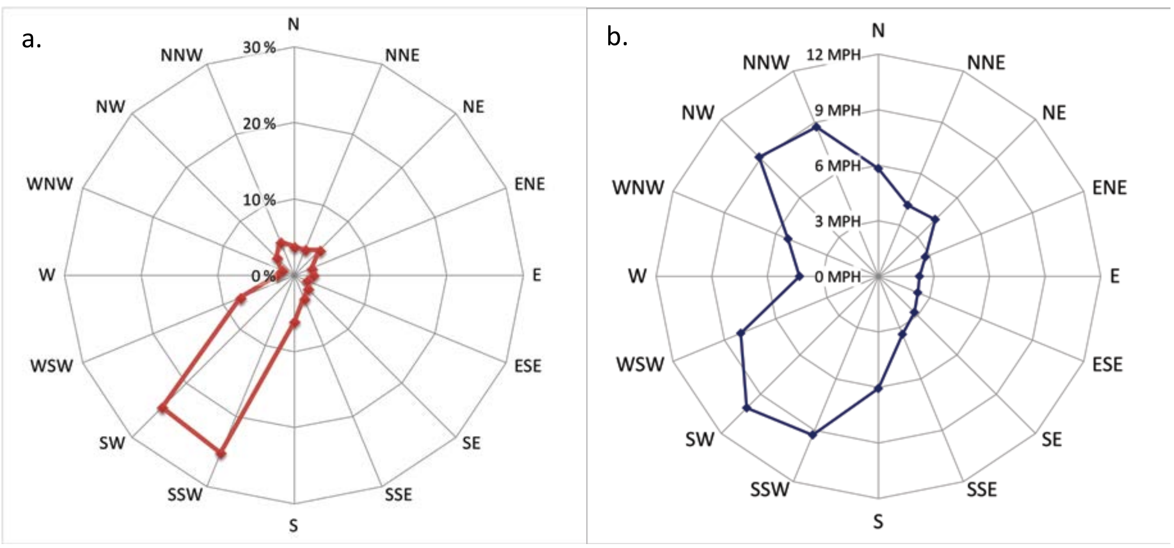

Figure 1.3. Wind at Blacklock station (BLL) near Little Honker Bay in Suisun Marsh for the year 2013. (a) Percent of wind from each direction and (b) average wind speed from each direction (DWR 2014). Over 60% of wind is southwesterly and southwest winds are the strongest.

It is likely that wind disturbance prevents plants from colonizing and stabilizing shallow mudflats that would otherwise be prime territory for marsh building. Winds cause water to pile up in these shallow bays, an effect referred to as “seiches” or “wind tides.” Material in the water collects along upwind banks, where currents are slower and water churns rather than washing through as in channels. Fine particles remain suspended, but heavier particles settle. In the case of Grizzly Bay, wind effects were probably a factor in rapid sediment accumulation following the Gold Rush. Prior to active flood management, seiches would have contributed to flooding of the marsh plain in high-water events much as they did in the Delta (Thompson 1957).

Wind has important effects on salinity gradients, sediment transport, food availability in the water column and vegetation. Salt water is denser than fresh water and tends to run along the bed of a channel underneath outflowing fresh water. When wind mixes the water, there is less stratification between salty and fresh water, which prevents salty water from moving as far upstream as it would in the absence of wind. If the air is calm while salt water travels upstream, higher salinities will persist even after the wind picks up again (Lacy and Monismith 2000). Wind disturbance increases turbidity, which shortens the distance light penetrates the water column. The turbulence generated by wind also circulates nutrients and plankton in the water column. Excessive wind is a stressor on vegetation and can have effects such as hardening of exterior plant surfaces and stunted growth. The winds passing over Suisun Marsh doubtless have major impacts on ecological processes on a number of levels.

The northeastern marsh: Nurse Denverton complex

The Nurse-Denverton complex in the northeastern part of Suisun Marsh occupies only about 10% of Suisun Marsh (24 km^2 or 5,900 acres), yet it is one of the most interesting subregions due to its unusual geomorphic features and relatively high aquatic productivity. Although its watershed is comparatively very small, with only about 65 km^2 (16,000 acres) of low-relief upland in contrast with 486 km^2 (120,000 acres) of upland with moderate relief contributing runoff to the western marsh, channels are well developed and relatively broad and deep. Partly because of its small watershed, hydrologic circulation is limited. Wind effects and hydrodynamics in Montezuma Slough also boost hydrologic residence time in this subregion, creating conditions conducive to a rich aquatic food web.

The larger sloughs in the Nurse-Denverton area cannot have been shaped by the diminutive tributaries present today. Contemporary watersheds are small in size and lack topographic relief, so they cannot deliver large or fast-moving inflows of water that could carve broad, deep sloughs. Similarly, present-day tidal action is not powerful enough to scour out large sloughs here. It is likely that the ever-shifting Coast Ranges were once configured in such a way that Nurse Slough was an outlet for, or deltaic branch of, a large river. The lower Napa River similarly may have been shaped by an ancient waterway on the scale of the contemporary Sacramento River (Elliott-Fisk 1993; Loeb 2011). The drainage divide between the Nurse-Denverton area and the Delta is only approximately three meters above sea level and is bordered on the north and south by hills uplifted in the recent geologic past.

Landscape features suggest that wind also is a major geomorphic driver in the Nurse-Denverton subregion. The gap in the Coast Ranges between the Vaca Mountains and Mount Diablo functions like a trough, channeling air over Suisun Marsh and the low-lying Montezuma Hills to the Lindsey-Cache Slough area in the Delta. Wind disturbance is probably what prevents marsh plants from colonizing shallow mudflats in oddly shaped Little Honker Bay, located at the end of the long, straight, southwest-northeast trending portion of Nurse Slough. Wind may also have been a factor in prevention of natural pond formation here because wind disturbance may have deterred ducks from visiting (Monda and Ratti 1988) and from puddling for extended periods of time.

Regardless of the process by which the sloughs were formed, their current configuration has major ecological implications. Small watershed size limits the amount of storm discharge that might flush through the slough network. Nurse Slough meets Montezuma Slough at nearly a right angle, and when incoming tides are moving rapidly or when outgoing winter flood waters are high, flow rushes through the larger and deeper Montezuma Slough so powerfully that the water itself acts like a dam. Due to momentum, water tends to push directly forward (northwest) rather than turning sharply to the northeast and flowing into the Nurse-Denverton region. This fast-moving water simultaneously obstructs slow-moving water at the mouth of Nurse Slough from flowing out into Montezuma Slough (Teejay O’Rear, personal communication, 2011). Seiches also affect physical processes here, pushing water toward the northwestern ends of long fetches away from the system’s outlet at the mouth of Nurse Slough[2].

Hydrologic isolation and related high hydrologic residence time resulting from the physical processes described above have persisted into the present, although effects of upstream water management, especially the salinity control gates, keep the area fresher and dampen natural fluctuations in temperature and other water-quality parameters. Today, water quality in the Nurse-Denverton region is the least variable and the region is among the most consistently fresh in Suisun Marsh (O'Rear and Moyle 2009). This subregion has some functional

[2] Effects of seiches during flood events would have been strong prior to levee construction in the Nurse-Denverton complex when floods caused water levels to rise and cover the marsh plain, likely creating excellent fish nursery conditions.

similarities to standing bodies of water where lack of through-flow promotes stable conditions and retention of nutrients. Cattle grazing in adjacent uplands may be increasing nitrogen and sediment inputs throughout the marsh, effects that would have proportionally greater impacts in the Nurse-Denverton complex than in other areas of the Marsh due to the lack of flushing. Fresher conditions and less fluctuation in water quality create an overall less stressful environment, one favorable to aquatic species less able to adjust to broad swings in environmental conditions.

Wind-driven hydrologic mixing increases dissolved oxygen and can boost productivity by distributing nutrients and food throughout the zone of mixing. Wind-driven mixing also keeps fine sediment suspended in the water column. This turbidity is an abiotic aspect of habitat from which some aquatic species benefit because a limited line of sight provides cover from visual predators, such as striped bass and birds, and security for predators relying on senses other than vision, such as sturgeon. Suspended sediment also mutes light penetration, which slows phytoplankton growth and reproduction.

Compared to other sloughs in Suisun Marsh, Nurse and Denverton sloughs have been observed to have relatively high diversity and abundance of fishes (O'Rear and Moyle 2009). Denverton Slough stands out as an example of high-functioning brackish aquatic habitat. It is a moderately sized waterway with concomitant channel complexity that has not been diked off at the mouth from larger downstream sloughs (as seen in Volanti Slough), although it is worth noting that upper Denverton Slough was straightened in the early 1900s to improve passage for boats carrying agricultural freight. For this reason, as well as the presence of shoreline dikes, managed wetlands on the marsh plain and grazing on adjacent uplands, the area is highly altered by any measure. Nonetheless, the Nurse and Denverton Slough aquatic and wetland ecosystems support a high diversity and abundance of fish and other organisms. A more thorough evaluation of ecological conditions here could inform Marsh conservation projects in the region.

The potential of the northeastern Nurse-Denverton subregion to accommodate sea level rise should not be overlooked. Sloughs and marsh plains in this area are bordered by sparsely developed, low-rolling hills. Parcels are relatively large, and well-placed protected areas could provide areas for marshlands to move up-gradient in response to rising waters. At the same time, terrestrial corridors from Suisun Marsh to Jepson Prairie and the northern Delta could be established.

The southern marsh: fringing California's great river

The fringing marsh on the Contra Costa County shore of Suisun Bay is at times considered part of Suisun Marsh, although it is not treated as such in this book. It is worth reviewing briefly because it provides a glimpse of what might have been an alternative future of the Marsh had it not been adopted by waterfowl hunters.

The Contra Costa fringing marsh occupies a ribbon of shoreline between Martinez and Pittsburg, where the southern bank of the Sacramento-San Joaquin River meets the northern foot of Mount Diablo. The watershed for this subregion includes Walnut, Mount Diablo, Upper Alameda and Marsh creeks, along with numerous smaller creeks and sloughs. At nearly 650 km2 (160,000 acres), the watershed of this strip of marsh is comparable in size to that of Suisun Slough. There is much more topographic relief, however, with mountainous terrain dropping steeply into the river and leaving little area for marsh plain development. Approximately 40 km2 (10,000 acres) of marsh exist here, compared to over 260 km2 (65,000 acres) north of the river.

As seen in early maps (Bache 1872; USGS 1896; USGS 1908), most historic sloughs in this region were highly sinuous, yet they were shorter, smaller, and less interconnected compared to sloughs on the north (Suisun Marsh) side of the river. Hydrodynamics were less complex, with abiotic conditions being driven strongly by events in the adjacent Sacramento-San Joaquin river channel, with some seasonal freshening provided by tributaries.

Pacheco Creek (figure 3.1) appears to have drained into large mudflats as depicted in the Bache 1872 map, although approximately 25 years later the same area is depicted by USGS as a mostly vegetated emergent wetland. Otherwise, shorelines on the two maps correspond closely, suggesting this discrepancy may point to a rapid change in land cover. Between 1896 and the present, the shoreline around the mouth of Pacheco Slough aggraded even further into former open water, indicating that this process is ongoing. This sedimentation process was likely driven by accretion of gold-mining sediment and may currently be driven by upstream erosion from inflowing streams. Unlike aggradation on Grizzly Island, dikes were not aggressively constructed to capture and drain new land in this fringing marsh; thus the area provides an example of progressive marsh development since 1850.

Today, uplands in Contra Costa County immediately adjacent to the fringing marsh are heavily industrialized, with development including oil refineries, power plants, aggregate mines and military installations. Railroads also pass through the region, but duck hunting clubs and agriculture were never developed in these marshes. As a result, marsh lands have not been intensively managed, and fewer dikes, diversions, ponds and roads have been constructed on the marsh plain. Flood control channels, water management ponds and numerous mosquito ditches are present, but, overall, the marsh plain is less degraded. Low-elevation marsh, high-elevation marsh and muted tidal marsh all are proportionally well-represented landscape components (SFEI 2012). Oil spills and pollution are ongoing concerns here, much as they are in marshes north of the river. The contrast between this fragmented industrial landscape with many pockets of marsh left to develop at their own pace and the dominance of duck club management in the marsh areas north of the river offers a window on how human impacts on greater Suisun Marsh may have progressed in the absence of duck clubs and persistent citizen advocacy for conservation and preservation.

Ecotone subregions

Additional process-driven subregions in Suisun Marsh are ecotones including the marsh-upland transition zone, ephemeral edge wetlands and tidal mudflats. Although they occupy less space than subregions described above, each contributes in an important way to ecosystem functions and biotic diversity. These wetlands and aquatic sites form along the periphery of the marsh plain and offer key habitat for many species.

The marsh-upland transition borders the marsh plain where soft, waterlogged peat soils give way to firm, dry ground. This wetland type is notably species rich, particularly in vascular plants. Soil composition, water content, inundation regime and salinity change rapidly over the short distance of transition, yielding a wide variety of microhabitats. Historically, this wetland zone constituted a nearly uninterrupted band that bordered the marsh plain as well as marsh islands with upland areas, such as Bradmoor Island. In the contemporary landscape, this transition zone is fragmented by roads, levees and other development. In many locations, plant diversity has been suppressed by grazing, flooding and farming. Where remnant marsh-upland transition zone wetlands persist, as on Rush Ranch, this landscape feature is observed to support a variety of mostly native plants and animals (WWR 2011).

Ephemeral edge wetlands historically dotted the marsh-upland transition zone and nearby low-lying uplands. Vernal pools and similar wetlands on stream floodplains were present, and alkali flats may also have existed. USGS topographic maps and the 1872 Coast Survey map provide clues about these former landscape features, which have since been converted to crop land, built upon or heavily grazed. Ephemeral edge wetlands undoubtedly harbored numerous rare species and are a landscape component that, while covering a small area, supported a disproportionate amount of biodiversity.

Tidal mudflats were present along the northeastern edge of Grizzly Bay, at the bay-ward tips of Joice and Morrow islands. As recognized worldwide, mudflats are critical foraging habitat for shorebirds and fishes, and, following similar worldwide trends, the extent of mudflats has been greatly reduced in the San Francisco Estuary by human modification. Their extent presumably was affected by Gold Rush sediment even in the earliest well-surveyed cartographic depictions. During the 1900s, areas that had been mudflats in the late 1800s were largely diked or otherwise converted to other uses or wetland types. In some cases, mudflats were colonized by plants and transitioned to marsh plain and/or fringing marsh due to net sediment deposition. Approximately 2.8 km^2 (700 acres) of tidal mudflats remain in Suisun Marsh (SFEI 2012), 17% of the 16.8 km^2 (4,100 acres) surveyed in 1866-1867 (Bache 1872).

Historical landscape summary

Numerous processes shaped the wetland landscape that early settlers encountered in Suisun Marsh, creating a mosaic of marsh plain, sloughs, ponds, uplands and transitional zones. Spatial and temporal variations in water quality supported a highly diverse flora and fauna with adaptations for living in a variable environment. Some of these physical and biotic characteristics have persisted into the present. Suisun Marsh is still a variably brackish system with diverse and abundant species, although many today are alien species. Other aspects of the physical and biotic environment have changed substantially since 1850.

Most of today's landscape features are easily recognized in even the oldest maps, as tides, river discharge and wind continue to dominate physical processes. Yet hydrology is substantially different than it was 150 years ago. Several moderately large sloughs (e.g., Roaring River, Grizzly, Frost, Island, upper Tree, Hastings, and Volanti sloughs) have been dammed off with dikes, affecting tidal action and connectivity for aquatic species. In channels that remain connected, circulation patterns have been altered by channel straightening, creation of new connections between sloughs and construction of agricultural canals, mosquito-control ditches and salinity control structures.

Human intervention since 1850 has dramatically altered distribution, quality and quantity of aquatic and wetland habitats, and has favored some species, especially ducks, over others. Peripheral ecotones, including the marsh-upland transition zone, ephemeral edge wetlands and tidal mudflats, have been most severely impacted, to the point that it is difficult to locate examples of the first two in the modern landscape. Undiked tidal marsh has been reduced dramatically as well, with only about 31 km^2 (7,700 acres) of the 225 km^2 (55,600 acres) present in the late 1800s remaining (SFEI 2012). The balance is diked and managed, largely preventing or reversing soil-building processes. Shallow, open-water environments attractive to waterfowl are much more extensive than they were historically, and they now exist throughout Suisun Marsh instead of being concentrated in the western portion. Overall, physical conditions in the mid-1800s through 1910 are significantly different from conditions today. In the following chapter, human-landscape interactions, including those that created modern conditions, will be considered in more depth.

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Chapter 2

Human-landscape Interactions in Suisun Marsh

Introduction

Suisun Marsh is about 6,000 years old and has been inhabited by humans throughout its history. Information gleaned from explorer's accounts, early maps, studies in anthropology, and other sources reveal major shifts in plant and animal distribution and abundance in response to fluctuations in the human population since the beginning of sustained European contact in the San Francisco area in the late 1700s. Documented landscape-scale ecological changes occurring both before and after the influx of Gold Rush settlers show that the Marsh landscape can change rapidly in response to our management actions.

Landscape interactions: native peoples

"Suisun" is the name of a southern Patwin people who lived in the vicinity of Suisun Marsh. This was reportedly the tribe's[3] chosen name and was the moniker used by early Spanish settlers. It is rumored to translate to "land of the west wind," although it is no longer possible to verify the accuracy of the translation (Arnold 1997). Native residents throughout the region subsisted on seeds, nuts, fruits, bulbs, birds, fish, shellfish, game and insects (Lightfoot and Parrish 2009).

[3] We recognize, following Lightfoot and Parrish (2009), that the complex social structure of California Indian groups does not fit well under the conventional rubric of "tribes," which implies a fairly rigid and hierarchical structure that was largely absent from the native peoples. We nevertheless label the groups as tribes for convenience and to follow conventional usage.

The record on specific human-landscape interactions is sparse, but there are enough clues to establish a sense of life on the Marsh before European contact.

The Marsh was clearly a valuable resource for food and materials. The San Francisco Bay region had likely been inhabited for 10,000 to 15,000 years (Erlandson *et al.* 2007) and was well populated in 1769. Some evidence suggests that native Californian peoples experienced population crashes in the 250 years prior to 1769 because the arrival of European diseases preceded explorers. Fluctuations in populations of native peoples would have had direct ecological consequences, causing plant and animal assemblages to vary in tandem (Rosenthal *et al.* 2007).

The area occupied by any one San Francisco Bay Area tribe at the time of European contact was usually small, estimated to be about 26 km^2 (6,400 acres). Villages were typically comprised of 40 to 100 people, though some were substantially larger. Population density depended somewhat on the carrying capacity of the surrounding landscape. José de Cañizares noted a settlement with about 400 inhabitants in the Carquinez Strait area in 1775, suggesting that food resources of river and marsh environments were abundant (Eldredge 1909). Population reconstructions for the San Francisco region point to denser populations in areas bordering marshes because they are exceptionally productive environments (Milliken 1991).

The Suisuns were not the only group relying on marsh resources. Neighboring tribes, and their local districts (given with contemporary place names), included the Carquin to the west near Benicia, the Tolena to the north in Green Valley, the Malaca to the northeast near Maine Prairie, the Anizumne to the east near Rio Vista, the Ompin to the southeast near Antioch and the Chupcan to the south near Martinez (Milliken 1991) (figure 2.1).

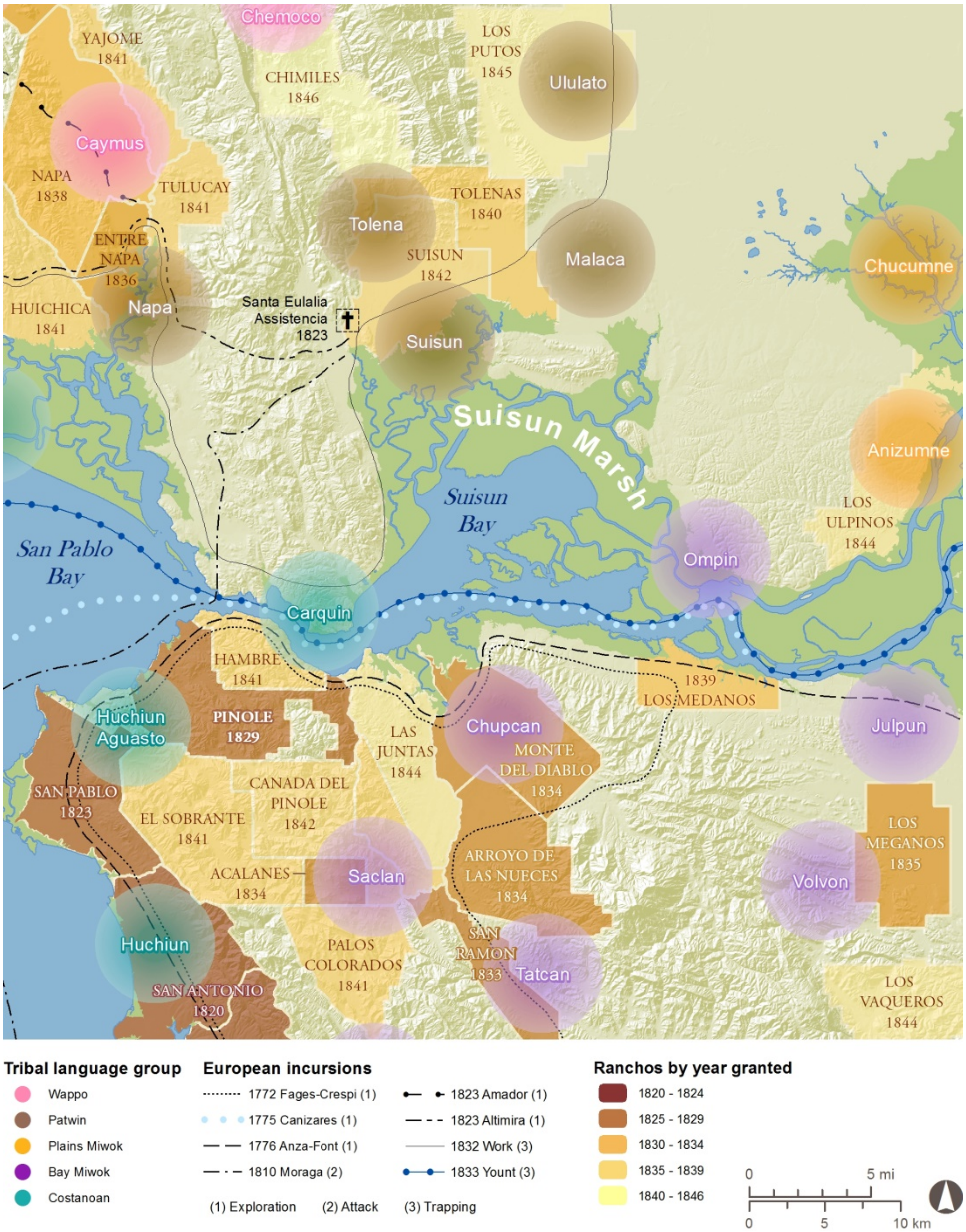

Figure 2.1. Shifting landscape pressures 1772 - 1846. Representation of known human presence intended for conceptual illustration. Circles show approximate centers of areas inhabited by tribal groups and colors represent Indian language groups (Milliken 1995). Also shown are early explorers' paths (Camp and Yount 1923; Eldredge 1909; Honton 2005; Maloney and Work 1943), the Santa Eulalia mission assistencia (Bowen 2009), Mexican land grants (BLM 1993; Shumway 1988), historical wetlands (San Francisco Estuary Institute (SFEI) 2012; Whipple et al. 2012), and topography (Gesch et al. 2002).

Native people were skilled boaters, crossing Carquinez Strait and San Francisco and San Pablo bays in small tule vessels. Suisun-area tribesmen regularly traversed the sloughs for both hunting and transport, as many accounts note the prevalence of tule rafts and canoes and the dexterity with which they were maneuvered (Eldredge 1909; Font 1776; Von Langsdorff 1814). One author specifically notes native hunting parties visiting Grizzly Island by boat in the mid-1800s (Mofras 2004).

Tules (California bulrush [*Schoenoplectus californicus*] and hardstem bulrush [*S. acutus* var. *occidentalis*]) were a multi-purpose construction material for people living anywhere near a tule marsh. In addition to boats, tules were used to make housing and storage structures, furniture, clothing, shoes, canoes, rafts, baskets, duck decoys, boat launches, mats and other things. Harvesting of tules promoted new growth from rhizomes and likely increased habitat diversity (Anderson 2005). Considering that population density was generally high around marshes and that many of these items were replaced or repaired annually or more often, cutting of tules for these numerous everyday objects would have affected habitat quality in substantial areas of marsh.

It is likely that Suisun-area tribes used fire as a landscape management tool in uplands and in the marsh to flush animals and improve visibility of game (Lewis 1993). Active fires and fire scars were noted throughout California by early European explorers (Crespi 1770; Font 1776; Menzie and Eastwood 1924); however, the purposes, frequency and spatial extent of burns in marshes are not well documented (Whipple *et al.* 2012). In uplands, burning clears brushy growth and encourages an oak savanna ecotype that makes harvesting plant resources and game more efficient (Anderson 2005; Lewis 1993). In marshes, burning similarly resets successional trends, and, as plants sequentially reestablish themselves, they provide habitat for a wide array of desirable species (Hackney and de la Cruz 1981). In the absence of fire, senesced vegetation becomes densely matted, excluding species that require more open habitat (Anderson 2005).

European explorers took close notice of native hunting and fishing methods in the region, and they were sometimes surprised at the efficacy of techniques quite different from their own. Examples of methods include pitfalls for large mammals (Camp and Yount 1923), snares for smaller mammals, deerskin camouflage for deer (Von Langsdorff 1814) and nets and weirs for catching large fish such as salmon and sturgeon (Font 1776; Mofras 2004). Nets also were used to capture birds (Maloney and Work 1943).

Waterfowl were prevalent of in the diet of people living near Suisun Marsh and all along the shores of the San Francisco Bay Estuary. Preserved whole birds stuffed with grass were offered to European visitors as a gesture of welcome or in trade (Treutlein 1972). Feathers and bird skins were also incorporated in clothing and ornamentation (Crespi 1770; Maloney and Work 1943; Von Langsdorff 1814).

People have interacted with and manipulated Suisun Marsh in ecologically significant ways, perhaps continually, for many thousands of years. Although records are sparse, it is evident that landscape management by native peoples 250 years ago was different in intent, methods and outcomes than management today. Abundance of game species and habitat mosaics in both uplands and the Marsh were influenced by thousands of years of human-landscape interaction. Procuring food and shelter from the landscape for (at least) several hundred people living on the shores of the Marsh put constant pressure on natural systems.

This pressure surely fluctuated along with human population, although it is not known if the number of people living around the Marsh in 1769 was high or low relative to the average population in preceding centuries. Hunting, fishing, foraging and active landscape management shaped the setting that early European explorers and trappers encountered in many ways, although Europeans did not always understand what they were seeing.

Spanish California 1769 – 1822: explorers, missions, and fur trappers

The earliest European explorers were focused on documenting routes for travel and assessing lands for settlement, thus any notes relevant to ecology of the region are typically motivated by one or both of these factors. Occasionally, journal entries were made on events that were outstanding in their experience, such as encountering large numbers of bears or being shaken by violent earthquakes. Journal accounts affirm many conditions we would expect European explorers to have found and also present novel information about the landscape. Early exploration near Suisun Marsh was carried out on foot along the south bank of the Sacramento River and by boat (Treutlein 1972, Eldredge 1909) (figure 2.1).

In 1772, members of the Fages party were the first Europeans to view Suisun Marsh. By land, they explored the Marsh by following its southern shore to the edge of the Delta east of Antioch before heading back toward Monterey. Traveling during early spring, Pedro Fages (in Treutlein 1972) described grassy hills with wildflowers, bears, deer, elk, and antelope; he saw smoke rising from numerous villages in the area. Looking down at Grizzly Bay, he notes, “we could see that the arm of the estuary, before it made its entry between the hills, forms a sort of large, round bay, wherein were seen two or three whale calves.” Fages also observed marshy lowlands and several islands with “good friable soil which can easily be drained of water” around the outlet of the Sacramento and San Joaquin rivers.

In August 1775, Don José de Cañizares, a member of Don Juan Manuel de Ayala’s crew, traveled by boat through Carquinez Strait and upstream to a location near Sherman Island. Regarding San Pablo Bay, he states, “It is not difficult to enter this bay, but going out will be difficult on account of the wind from the southwest” (Eldredge 1909). This is not a surprising observation, intended as a guide to sailors that might follow him, but prescient nonetheless. His account of Carquinez Strait mentions natives who “presented us with exquisite fishes (amongst them salmon), seeds, and pinole.”

They report that Suisun Bay is a less promising port than Southampton Bay, located west of Benicia, because “it would be difficult to obtain wood, which is far from the shore. All of the eastern coast is covered with trees; that to the west is arid, dry, full of grasshoppers, and impossible of settlement.” The description of the Sulphur Springs Hills, north of Benicia, as parched and grasshopper ridden in August is in keeping with conditions today, but the account of a tree-covered eastern shoreline, along the Montezuma Hills north of Collinsville, is unexpected. Their map depicts extensive stands of trees on the Montezuma Hills, on par with forests indicated in the same map around present-day San Rafael, Oakland-Hayward and the northeastern foothills of Mount Diablo (Cañizares 1781; Eldredge 1909).

Freshwater sources and navigability of rivers were hot topics in the late 1700s. An early name for Grizzly Bay was “Puerto Dulce,” or “Freshwater Port,” a designation made by sailors eager to mark the transition zone between salt and fresh water, which occurred in the vicinity of Suisun Marsh (Eldredge 1909; Font 1776; Treutlein 1972). For a time, there was some debate as to whether Montezuma Slough was a substantial river of its own or merely a branch of the Sacramento River (Mofras 2004). The Sacramento and San Joaquin rivers and the tule marshes of the Delta were major barriers to northward and eastward travel, influencing patterns of Spanish exploration and settlement in the pre-Gold Rush era.

The written record provides us with a fascinating, if narrow, narrative on pre-colonial conditions. For example, in April 1776, at the northeastern foot of Mount Diablo, tule elk (*Cervus canadensis* ssp. *nannodes*) were described by Pedro Font (1776) as follows:

> On descending to the plain we saw, near the water and about a short league away, a big herd of large deer, being, I think, what they call "buros" in New Mexico. They are about seven spans high, and have antlers about two yards long with several branches. Although an effort was made to get one, it was impossible, because they are very swift, and the more so at this time as they had shed their great antlers, which undoubtedly they do at seasons judging from the many horns that we saw lying about. All this region abounds in these deer; and the tracks, resembling those of cattle, that we found this day and the next, make it appear as if there was an immense herd of cattle thereabouts.

Tule elk are mentioned in early accounts more frequently than are pronghorn antelope (*Antilocapra americana*) or mule deer (*Odocoileus hemionus*), possibly because they were more prevalent when European explorers arrived or because they were more visually striking animals. Grizzly bear (*Ursus arctos horribilis*), beaver (*Castor canadensis*), and river otter (*Lontra canadensis*) were among other mammals in high abundance in and near Suisun Marsh around 1800. It is possible that reductions in populations of native peoples due to waves of disease meant that animal abundance in the 1770s was relatively high in comparison to decades or centuries previous (Preston 1998). Sizeable populations of such animals would have had meaningful landscape impacts, exerting grazing pressure on plant communities, trampling pathways through the marsh, wallowing in standing water, dust bathing in salinas and affecting soil processes.

Soon after the first European explorers marched along the shores of San Francisco Bay, Spaniards began to settle the region, building missions, presidios and pueblos. The first non-Spanish settlers appeared shortly thereafter, among them fur trappers and whalers. In Suisun Marsh, this period involved a major decline in human population and over-exploitation of fur-bearing wetland species such as beaver and river otter.

Following the establishment of Mission San Francisco in 1776, Mission Santa Clara in 1777 and Mission San Jose in 1797, native peoples of the San Francisco Bay region were assimilated over the course of several decades. The Suisuns actively resisted conversion between 1800 and 1810, becoming revered by neighboring tribes - and notorious among Europeans - for their unwillingness to cooperate[4] (Schoolcraft *et al.* 1857). Many individuals who left Mission San Francisco, considered runaways by the Spanish, came to Suisun to avoid recapture. For a time, the Suisun Marsh area was perceived as a frontier landscape by both natives and colonists. Between 1810 and 1816, the Suisuns' will to resist waned, and most abandoned their villages for Mission Dolores in San Francisco. This event was disheartening for other tribes in the region. Once the formerly steadfast Suisuns ceased to resist missionization, surrounding tribes joined the missions in rapid succession (Milliken 1991).

Mission establishment, beginning in 1776, led to major changes in landscape ecology. By the 1830s, the lands of San Francisco Bay region were largely depopulated, both because tribes

[4] By the mid-1800s the relationship between Suisuns and colonists had reversed, with the Suisuns being favored by Mexicans (particularly Mariano Vallejo) for their character and abilities. One author notes that, "In Petaloma [sic] valley, the original inhabitants are reduced to almost nothing, and they have been replaced by the Indians of Suisun, from the bay of that name, above Benicia" (Schoolcraft and others 1857).

had left their villages for the missions and because measles, cholera, smallpox, dysentery and other introduced diseases had killed an enormous number of people (Ahrens 2011; Milliken 1995; Patterson and Runge 2002). Both emigration and disease-related death were centered geographically around missions, radiating outward temporally and in decreasing degrees of severity. Due to the uneven spatial distribution of impacts, estimates of a 20% state-wide native population decline for this time period (Cook 1976) likely understate the much more dramatic decrease in population on the shores of the San Francisco Bay Estuary.

In 1833, George C. Yount traveled through central California on a trapping expedition and witnessed the aftermath of a major malaria outbreak. After relaying bleak scenes including abandoned villages, the “bones of untold thousands” lying in the valleys and encounters with despondent, starving survivors, he reflects on the effects of nearly 40 years of human depopulation on regional ecology. As recorded by Clark (in Camp and Yount 1923):

> In 1833 – Benicia was visited and has been thus described: It was then nothing more than a wide and extended lawn, exuberent [sic] in wild oats and "a place for wild beasts to lie down in" – The Deer, Antelope and noble Elk held quiet and undisturbed possession of all that wide domain, from San Pablo Bay to Sutter's Fort … The above named animals were numerous beyond all parallel – In herds of many hundreds, they might be met, so tame that they would hardly move to open the way for the traveller [sic] to pass – They were seen lying, or grazing, in immense herds, on the sunny side of every hill, and their young, like lambs were frolicing [sic] in all directions – The wild geese, and every species of water fowl darkened the surface of every bay, and frith, and upon the land, in flocks of millions, they wandered in quest of insects, and cropping the wild oats which grew there in richest abundance – When disturbed, they arose to fly, the sound of their wings was like that of distant thunder – The Rivers were literally crouded [sic] with salmon, which, since the pestilence had swept away the Indians, no one disturbed – It was literally a land of plenty, and such a climate as no other land can boast of.

One point of interest in this description is that, in 1776, Font and his men found elk hiding in the tules notably shy of humans, yet Yount found emboldened herds covering nearby hills less than 60 years later. Today, imagining either scene unfolding in the hinterlands between Mare Island and midtown Sacramento requires a certain suspension of disbelief. Yount's impression was echoed by other travelers during this era, and, even if his account contains some embellishment, it points to profound changes in the landscape brought by a sudden drop in human population. In sum, large-scale environmental responses included decreased hunting pressure on animal populations, increased grazing pressure on grasslands, decreased foraging and manipulation of plant communities by native peoples. With an increase in prey, large predators such as grizzly bears increased in abundance as well (Preston 1998).

Yount surveyed the hills around Suisun Marsh in a key period of ecological transition. In 1833, missions had substantially diminished the human population, but ranchos had yet to disperse their vast cattle herds into the area. Not a single large-scale rancho existed north of San Francisco Bay, and the nascent San Antonio, San Pablo and Pinole ranchos, located between the East Bay Hills and San Francisco Bay shoreline, were the only ranchos east of the bay. Missions were established in San Rafael in 1817 and Sonoma in 1823, but these were relatively remote from Suisun. In about 1825, a small rancho and *asistencia*, or sub-Mission, near present-day Rockville was established. This tiny outpost was run by Christian Indians who were charged with raising crops, running cattle and converting non-Christians from outlying tribes (Bowen 2009).

The mission era marked the onset of steady introductions of European animals such as cows, goats, pigs, horses and sheep into the environment. Old World plant species were likely already a part of California's flora when the first explorers arrived, but abundant sustained introductions during the mission era caused alien plants to colonize prodigiously (Mensing and Byrne 1998; Minnich 2008; Preston 1998). Much like effects on human populations, these changes radiated outward from missions and ranchos.

An abundance of beaver and river otter was trapped in Suisun Marsh during this period, with reports of 4,000 beaver taken from the Marsh area in 1830 alone (Mofras 2004). In the spring of 1833, Trapper John Work and his party camped on the periphery of the Marsh for a few weeks. His journal affirms the presence of numerous deer, antelope, elk and bear but only a handful of native people. His party killed at least 17 bears during their stay. Work was keenly interested in assessing the abundance of beaver and he gives us this characterization of the Marsh: "[Suisun] bay is destitute of wood, it has the resemblance of a swamp overgrown with bulrushes and intersected in almost every direction with channels of different sizes and except the want of wood apparently very well adapted for beaver, the people say that beaver are to be found among the rushes" (Maloney and Work 1943). Beaver and river otter were both hunted aggressively, reducing their abundance to very low numbers in Suisun Marsh and the Delta before demand for their pelts waned.

Insofar as wildness is defined as lack of human intervention, conditions in Suisun Marsh in the early 1830s were perhaps wilder than they had ever been. Game populations soared in the absence of hunting pressure and active habitat management by humans. Land cover and ecosystem functions no doubt were affected by the cease in intentional fire-setting for vegetation management and by the spread of nonnative plants. This period was followed by settlement activities that further affected regional ecology (Table 2.1)

Table 2.1. Early European exploration and settlement

Year	Event	Description
1542	Territory claimed by Spain	Juan Rodriguez Cabrillo explored Pacific coast of North America, Spain claimed Californias.
1772	1st European land expedition encountered Suisun Marsh	Traveling along the south shore of Suisun Marsh, the Fages party encountered friendly Indians harvesting spring-run salmon. They prepared a map of San Francisco Bay, San Pablo Bay and Suisun area.
1775	1st Nautical expedition: The San Carlos arrived at San Francisco Bay	The *San Carlos* was the first ship to pass through the Golden Gate. Lieutenant Juan de Ayala was injured, so first pilot, Don Jose Cañizares, and second pilot, Don Juan B. Aguirre, explored and mapped Suisun Bay.
1776	2nd European land expedition encountered Suisun Marsh	Suisun south shore traversed by Captain Juan Bautista de Anza, Father Fray Pedro Font and their party. They attempted to trade glass beads for fish, but Indians would only trade for clothing.
1776	San Francisco Presidio and Mission established	Construction of San Francisco Presidio and Mission Dolores begun.
1806	Russians visited San Francisco	Russian party led by Langsdorff lodged on San Francisco peninsula and traveled by boat to South San Francisco Bay. Their goals were to obtain supplies and gain intelligence on Spanish California.
1809	Carquins moved to mission at San Francisco	Carquins abandoned villages for Mission Dolores, leaving no buffer between Suisuns and Missionaries
1810-1822	Suisuns moved to mission at San Francisco	Suisuns abandoned villages to join mission at San Francisco. Those who didn't want to go to the mission moved east to join other Patwin tribes.
1812	Russian settlement at Fort Ross founded	Spanish perceived Russian settlement as a territorial threat, increasing their determination to maintain missions.
1817	Mission San Rafael founded	Mission San Rafael Arcangel established as a sanitarium in 1817, and then became a full-fledged mission in1822.
1823	Mexican Republic instated	Precursor to fall of missions.
1823	Altimira explored north bay; established mission in Sonoma	Father Jose Altimira searched for a mission site between Petaluma and Suisun, and then founded Mission San Francisco Solano in Sonoma. This is the only mission established during Mexican rule.
1824	Santa Eulalia Asistencia established by Altimira	Jose Altimira established the Santa Eulalia Asistencia and rancho near Rockville. This is probably the first sustained Spanish influence (cattle, plants, culture, etc.) near Suisun Marsh.
1833	Yount trapping foray	George Yount traveled through Suisun area while hunting beaver and otter.
1833	Work Expedition	John Work's expedition camped at Suisun Creek while members went to the mission at Sonoma for ammunition.
1840-1846	Mexican land grants near Suisun	Cattle ranching increases; Suisun area ranchos included Suisun, Tolenas, Los Ulpinos, and Chimiles totaling over 269km^2 (66,000 acres).

Alta California: ranchos of the Mexican Republic 1822 – 1848

Between the late 1830s and 1848, the San Francisco Bay-Delta region experienced the rapid proliferation of ranchos (figure 2.1). Though the effects took a few years to reach the extremities of Alta California, the transition from Spanish-chartered missions, presidios and colonies to Mexican territory in 1821 changed more than the area's socio-political landscape. Domesticated animals, particularly cattle, became the basis for California's economy. During the 22-year span of the Mexican era, over six million cow hides were shipped from California (Hackel 1998). Vast, loosely contained herds of cattle put increasing pressure on native plant populations and eventually displaced native grazers (Preston 1998).

Mexican-style ranchos were short-lived in the Suisun area, because all were granted in the decade prior to the Gold Rush (figure 2.1). This was enough time, however, for a small herd of cattle to multiply into the thousands (Menzie and Eastwood 1924; Von Langsdorff 1814). Ranchos in the region were not located in the Marsh proper, although it was customary to allow cattle to roam freely and use any available freshwater sources as watering holes.

Diseños and Land Case maps drawn for legal purposes in the 1840s show the beginnings of hydrologic management in areas adjacent to Suisun Marsh. In these years, the first water diversions were constructed to irrigate small plots of vegetables and grain.

Trapping of fur-bearing animals continued during the Mexican era but tapered off gradually. The Mexican government made business increasingly difficult for foreigners, and over-trapping had reduced populations of the most desirable species, such as beaver and river otter, to unprofitable levels by the 1840s. At the same time, market demand for pelts was dropping. The Russians abandoned Fort Ross in 1841 and Hudson's Bay Company closed their

San Francisco office in 1846 (Maloney 1936; Ogden 1933). Resident Californians continued trapping at reduced levels, however, keeping populations of target species low.

The human population and their landscape impacts shifted fundamentally in this time frame, moving from hundreds of people engaged in active landscape-scale management (burning, plant harvest and maintenance) for preferred native species to a handful of residents farming cattle and vegetables and then to large-scale rancho development. As of 1848, the Marsh plain and sloughs were still functionally intact, with only minor modifications for irrigating small-scale agricultural plots in adjacent uplands.

Early American California: 1848-1900

Between 1848 and 1850, California became a US territory, underwent explosive growth with the Gold Rush, and was granted statehood. Hundreds of thousands of people poured into the San Francisco region and the pace and extent of landscape-level change mushroomed. Suisun Marsh was not a focal point for these changes, but it was on the immediate periphery. Sustained intensive waterfowl hunting, farming, settlement, land speculation, industrialization and militarization all came to the Marsh in this era, at which time it began to look and function like the Marsh we are familiar with today.

Those who arrived early on found a landscape much like the one described by Yount in 1833. After 1849, however, many animal species rapidly declined both in abundance and distribution: birds, elk, antelope, deer and bear were killed for subsistence, sport and for sale at market. Again, the spatial effects of settlement radiated outward temporally and in severity, this time from San Francisco, Sacramento, and the gold mines of the Sierra Nevada. In 1855, the following descriptions were made (Newberry 1857):

> In the rich pasture lands of the San Joaquin and Sacramento, the old residents tell us, it [tule elk] formerly was to be seen in immense droves, and with the antelope, the black-tailed deer, the wild cattle, and mustangs, covered those plains with herds rivalling [sic] those of the bison east of the mountains, or of the antelope in south Africa.
>
> Though found in nearly all parts of the territory of the United States west of the Mississippi, it [antelope] is probably most numerous in the valley of the San Joaquin, California. There it is found in herds literally of thousands; and though much reduced in numbers by the war which is incessantly and remorselessly waged upon it, it is still so common that its flesh is cheaper and more abundant in the markets of the Californian cities than that of any other animal… In the Sacramento valley they have become rare, and the few still remaining are excessively wild.

Hunting of Suisun Marsh waterfowl for the San Francisco market began around 1859. Market hunters were opportunists, profiting by harvesting abundant waterfowl from unregulated wildlands to feed the growing human population in San Francisco (Arnold 1997). They were not systematic in recording their kills so their accounts cannot be used as an indication of relative species abundance. Generally, market hunters' descriptions of bird populations continue in the same vein as descriptive accounts prior to 1849, further corroborating the productivity of the region.

With the Swamp Land Act of 1850, Congress granted "swamp land" - in other words, marshes - to the State of California, thus facilitating reclamation of wetlands. This legislation instigated a rush to patent, drain, dike and cultivate marshes. Marshes nearer to population centers were claimed first; thus Suisun Marsh initially was not a target for reclamation and land development. Settlement did come eventually, however, as some farmers sought to recreate the wild success of early agriculture in the Delta.

Lands were patented, surveyed, parceled out and sold beginning in the late 1800s. Farms appeared throughout the southeastern marsh, at the western foot of the Potrero Hills and in the northeastern Nurse-Denverton Slough region. The era of reclamation in Suisun Marsh was less comprehensive than in the Delta, but its effects are still evident in today's landscape. By the 1880s, reclamation districts had been organized and dike and levee construction to protect agriculture was well underway. Most construction was completed before 1920; by 1930, 181 km^2 (44,600 acres) had been enclosed by levees (Miller *et al.* 1975).

During this same period, the marsh plain was increasing in size because of the deposition of sediment washed down from hydraulic gold mining in the Sierra Nevada, allowing enterprising landowners to dike off new shoreline. Due to the sediment washed out of the Sierra Nevada by gold mining operations, reclamation efforts between 1900 and 1953 were able to increase the size of Grizzly Island by nearly 20 km^2 (5,000 acres), or 40% (USGS 1999) (figure 2.2). Today, the southwestern portion of Grizzly Island supports annual and perennial grasses and is primarily used for tule elk pasture.

Suisun Marsh's location approximately midway between San Francisco and Sacramento made it a convenient place for ships to take on agricultural products for urban markets in the mid- to late 1800s when waterways were primary shipping routes. For a time, agriculture in Suisun Marsh followed the same trajectory as in the Delta. Settlers constructed boat landings at numerous locations that enabled export of dairy, cattle and agricultural products. Building

Figure 2.2. Sediment deposition in Grizzly Bay, in conjunction with diking, has added nearly 20 km^2 of land area to Grizzly Island since the Swamp Land Act of 1850. Dates refer to map publication, not levee construction. Contemporary topography and bathymetry are shown (U.S. Geological Survey 1949 [1980]; Metsker 1953; U.S. Bureau of Land Management 1993; Gesch et al. 2002; California Department of Water Resources 2007; Boul et al. 2009; Foxgrover et al. 2012).

infrastructure to control tides and flooding in wetlands was labor intensive but could potentially pay off when nutrient-rich marsh soils produced high crop yields. As in the Sacramento-San Joaquin Delta, water for irrigation was abundant. Notably, water from wells and diversions in Suisun Marsh was consistently fresh enough for irrigation of berries, fruit trees, wine grapes, oats, barley, corn, beans, hay and asparagus, and for the watering of cattle and pigs from the inception of agriculture in the late 19th century through the early 20th century. Additionally, tules and California cordgrass (*Spartina foliosa*), for use as packing material, and clay, for use in the ceramic industry, were exported from the Marsh (Frost 1978).

Crop yields from the early years of farming were good, but, beginning in the late 1920s, exterior economic pressures and increasing salinity driven by droughts and upstream water diversions led to the eventual decline and abandonment of farms. There was a short-lived move to dairying, but today agricultural activities only take place on upland areas adjacent to the Marsh. Frost (1978) noted that, in 1927, "[The Baby Beef Company's] willingness to buy land on [Grizzly] Island, combined with the depression and Shasta Dam cutting down the fresh water supply, began a decline in dairying on Grizzly Island. The idea of owning duck hunting clubs was also gaining in popularity." The west side of the Marsh also was patented and some efforts toward reclamation were undertaken, but farming never took hold there as it did in the southeastern marsh. The geography of the western marsh, with its numerous natural ponds, attracted both ducks and duck hunters.

Duck hunting and railroad construction went hand-in-hand. Wealthy San Franciscans hunting the Marsh wanted quick transportation. A railroad line running directly through the Marsh - and to the doorsteps of the best clubs - was rumored to be mile for mile the most expensive track in Southern Pacific's history because substantial stretches repeatedly sank into the soft peaty soils (Arnold 1997). As reported 34 years after construction began (AP 1912):

> "Southern Pacific trains resumed travel today over the section of the Suisun [M]arsh, which swallowed up the track Friday. The marsh had sunk about twelve feet, for a stretch of more than fifty feet. The Suisun [M]arsh has presented one of the most puzzling problems with which the officials of the division of the road have had to deal. The 3000 feet of track across it has frequently sunk and many attempts to build a firm foundation for the tracks have failed."

Railroad construction at the turn of the century spurred land speculation and development in adjacent areas but development of Suisun Marsh was staved off. Some threats were avoided by luck, some by citizen action and others because the people proposing changes were merely charlatans intending to defraud unwary investors (Table 2.2). An increased awareness of socio-economic values of wetlands finally led to preservation agreements that have protected the Marsh for the past 40 years.

20th Century: advent of the conservation ethic

Duck clubs directed landscape change in Suisun Marsh throughout the 20th century. Club members' persistent advocacy thwarted numerous campaigns to industrialize the area (Table 2.2) and duck club management practices expanded habitat for ducks and have resulted in a far "softer" landscape (as opposed to an urbanized, "rigid" or "hardened" landscape) than in former Delta and San Francisco Bay tidal wetlands. In the Marsh, wetland habitat managed primarily for waterfowl supports a broad array of species and holds greater potential for restoration, rehabilitation, and/or reconciliation. At the same time, duck clubs have engineered the landscape for their own purposes, altering ecological processes significantly. Islands have been diked and ponds planted with and managed for non-native plant species preferred by sport waterfowl (Arnold 1997). Management legacies include subsidence of peat soils due to pond leaching cycles and occasional but recurrent fish kills when anoxic pond water is released into adjacent sloughs. Increasing pressures brought by sea level rise will exacerbate existing problems.

Table 2.2. One hundred thirty years of threats to Suisun Marsh and nearby areas.

Year	Event	Description
1846	Montezuma City	Montezuma City, intended to be a bustling Mormon colony, founded by Lansing W. Hastings. The plan never came to fruition.
1847	City of Francisca (Benicia) Founded	A land speculator named Robert Semply planned a sprawling city in the present-day location of Benicia.
1848	Suisun City Founded	Started as a bustling center for shipping via water and rail, but economy faltered after city was bypassed by highway I-80 in 1963
1850	New York of the Pacific (Pittsburg) Founded	Colonel Jonathan D. Stevenson founded "New York of the Pacific" at present-day site of Pittsburg, hoping for a booming metropolis to rival New York City.
1853-1854	Benicia declared capital of California	Benicia held sway as California's capitol for nearly 13 months. It would have become a much larger city if the capitol had not been moved to Sacramento.
1860s	Earliest salinity control planning	First discussions about shutting tide water out of Suisun Marsh to control salinity occur.
1860s	Collinsville (Newport City) Founded	Three successive owners plan large town at present-day Collinsville. The town perpetually failed to thrive.
1880	Carquinez Strait Tidal Barrier	State Engineer W.W. Hall proposed a tidal barrier across Carquinez Strait to prevent salt water intrusion.
1912-1913	Calhoun's Solano City swindle	Patrick Calhoun invested over $1 million of public utility money in publicity and creation of a navigable channel to "Solano City" and "Solano Irrigated Farms" at the upstream end of Lindsey Slough. Later transfers ownership of worthless shares in "Solano Irrigated Farms" to utility to compensate for money he took.
1921; 1924	Dam from Richmond to San Quentin	Captain C.S. Jarvis of USACE proposed massive dam and lock project to turn San Pablo Bay and upstream waters into a giant freshwater reservoir.
1946	Reber Plan	John Reber presented the "ultimate solution" to Bay-Delta management "problems." His plan included a dam from San Quentin to Richmond, a 2000-foot-wide causeway south of the Bay Bridge, ship locks, and a giant dredged ship channel along the east bay shoreline. $2.5 million USACE feasibility study undertaken. Drawbacks determined to outweigh benefits. Two lasting vestiges exist: the Bay circulation model in Sausalito and the Bay Conservation and Development Commission (BCDC).
1974	Giant garbage dump	Proposal was made to barge large quantities of garbage from urban areas to Potrero Hills. Would have involved major dredging and channel straightening in the Marsh. Present day operation uses trucks.
1975	Dow Chemical Plant	Dow Chemical proposed $500-million project in Collinsville. Construction was fought down by concerned citizens and would have required 65 government permits; a sign of changing attitudes about the environment

Sources: (AP 1974; AP 1977; Arnold 1997; Hogan and Papineau 1980; Stone 1996)

While efforts have been made to maximize the potential of Suisun Marsh to support migrating waterfowl, landscape change has occurred on all sides. Remarkably, the Marsh managed to avoid the sweeping conversion of wetlands to urban, agricultural and industrial uses seen elsewhere in the San Francisco Bay Estuary. Increased awareness of environmental issues by the general public has buoyed legal protection for the Marsh (Table 2.3). Compared to

Table 2.3: Environmental legislation, actions, and agreements affecting Suisun Marsh

1963	Suisun Resource Conservation District Formed
1965	San Francisco Bay Conservation and Development Commission formed
1970	Four-Agency Memorandum of Agreement
1972	US Federal Legislation: Clean Water Act, Endangered Species Act
1974	Nejedly-Bagley-Z'Berg Suisun Marsh Protection Act (SMPA)
1976	Suisun Marsh Protection Plan
1977	CA State Assembly Bill 1717: The Suisun Marsh Protection Act of 1977
1978	SWRCB Water Rights Decision 1485
1979-1980	Roaring River and Morrow Island Distribution Systems and Goodyear Slough outfall constructed
1984	Plan of Protection for the Suisun Marsh
1987	Suisun Marsh Preservation Agreement (SMPA)
1988	Suisun Marsh Salinity Control Gates constructed
1990-1995	Planning for the Western Salinity Control Project
1991	Cygnus and Lower Joyce facilities constructed
1994	Bay-Delta Accord initiates formation of CALFED
1995-1998	SWRCB Water Quality Control Plan
1995	Amendment Three to the SMPA
1999	SWRCB Water Rights Decision 1641
2000	Draft Jeopardy Biological Opinion
2000	CALFED Suisun Marsh Charter
2001	Suisun Marsh Charter Implementation Plan
2003	Habitat Management, Preservation, and Restoration Plan
2004	Bay Delta Science Consortium Suisun Marsh Science Workshop
2011	Suisun Marsh Habitat, Preservation, and Restoration Plan

the Delta, Suisun Marsh lacks extensive reinforced slough and channel banks, heavily fortified levees, extreme hydrologic manipulation and largely agrarian land use. Compared to wetlands on the shores of San Pablo and San Francisco bays, it lacks major dredge-and-fill projects, shipping ports and industrial sites. These landscapes are civil-engineered endpoints, hardened in ways that make them poor candidates for wetland ecosystem restoration. One exception would be salt evaporation ponds, which present similar potential for reintroduction of tidal action. Large-scale restoration projects are currently underway at former salt ponds north of San Pablo Bay and near South San Francisco Bay (Rogers 2013). The presence of less-altered wetland ecosystems in Suisun Marsh is one reason developers look there for mitigation sites when wetlands are eliminated elsewhere. Suisun Marsh's relative importance for wildlife increases with every nearby parcel of wetland converted to another use.

Construction of hydrologic infrastructure upstream of Suisun Marsh, including the Central Valley Project and the State Water Project, has had serious effects on the quantity and quality of water entering the Marsh. In the mid-1970s, civil plans to increase diversions in the Sacramento-San Joaquin Delta were expected to raise salinity in the Marsh, which was perceived as a threat to water-quality conditions required for the maintenance of waterfowl populations. The Suisun Marsh Plan of Protection and Water Rights Decision 1485 addressed this threat with yet more engineering, clearing the way for construction of major water distribution facilities in the Marsh. The salinity control gates and Roaring River and Morrow Island distribution systems, which increase the net inflow of fresh water, were mandated by this legislation (Sweeny and Spencer 1984).

Entering an era of multispecies management

In 1976, the San Francisco Bay Conservation and Development Commission established the Suisun Marsh Plan of Protection, a mitigation measure meant to compensate for impacts of major water projects on California's Central Valley. This was the beginning of a new management approach wherein government agencies began seriously investing in the Marsh's conservation potential. Most efforts have aimed to bolster waterfowl populations, but preserves have also been established to encourage locally restricted special status species such as Suisun thistle (*Cirsium hydrophilum* var. *hydrophilum*), salt marsh harvest mouse (*Reithrodontomys raviventris*) and Suisun shrew (*Sorex ornatus sinuosus*). With endangered species awareness comes monitoring, and the Marsh has been the site for hundreds of studies, covering topics as diverse as sediment cores and jellyfish invasions.

Key implications of Suisun Marsh historical ecology

For its entire history, Suisun Marsh has experienced both wetter and drier episodes lasting a few years to hundreds of years. This inherent regional variability is likely to increase when combined with the predicted effects of climate change. The fairly benign, largely freshwater conditions experienced in the past 150 years appear to be an anomaly.

1) Suisun Marsh is a complex landscape. It has never been simply one monotonous tule wetland, rather it is composed of many land cover types such as ponds, salinity gradients, sloughs, marsh plain, upland transition zone, and edge wetlands. This variety

is generated in great part by geomorphic diversity. This habitat diversity has favored a high richness and abundance of fish, wildlife and vascular plants.

2) Even when the earliest explorers surveyed the islands and waters of Suisun Marsh, this vast wetland mosaic was in flux. There has never been long-term stasis in the Marsh at geologic or even human time scales. It is a naturally dynamic system that responds quickly to human-induced change, an intrinsic quality can be leveraged for ecosystem restoration.

3) There is no such thing as a "pre-management" Marsh. Native peoples had strong interactions with the Marsh landscape, modifying it in many ways such as the pruning, harvesting and burning of plants, reducing wildlife populations through hunting, and modifying animal behavior and distribution through resource manipulation. Their management, in tandem with landscape interactions with beaver, elk, waterfowl and other vertebrates, likely resulted in a tidal marsh characterized by moderately sized expanses of open water and patches of tules in different stages of succession at all times.

4) The history of Suisun Marsh suggests that management of duck clubs and wildlife areas will eventually have to change, even in the absence of climate change. Freshwater inflow is likely to decline and/or become more variable, while subsidence of non-tidal lands and pollution of Marsh sloughs will need to be halted. Such a regime shift in management is historically compatible with past major changes in Marsh management.

5) Connectivity to outlying habitats was, and continues to be, critical in allowing Suisun Marsh to meet needs of native migratory mammals, birds and fishes. Plans to use Suisun

Marsh wetlands to compensate for wetland or protected species loss elsewhere through mitigation and habitat restoration projects will need to take into account the importance of interconnectedness with the larger landscape.

In Summary: Was the pre-management Marsh different?

Compared to the nearby Delta, Suisun Marsh *looks* more natural and is often perceived as a "green" space minimally altered by humans. The lack of conspicuous urban development tends to mislead casual observers into thinking that the entire marsh area is managed public land existing in a natural state. In fact, less than 20% of the Marsh is public land. Remaining areas are privately owned, primarily by duck hunting clubs. Conservation on both private and public land in Suisun Marsh most often means managing and/or creating habitat to attract waterfowl, with a few publicly owned reserves managed for special-status species.

Suisun Marsh was very different before the introduction of hydrologic infrastructure and modern landscape management. Salinity levels in bayward portions of the Marsh varied more than they do today. In the absence of reinforced dikes, major precipitation events caused widespread flooding of the marsh plain. Although sea level was rising during most of the early history of the Marsh, sediments were accreting at a roughly commensurate rate. The configuration and proportion of habitats such as ponds, marsh plain and mudflats were significantly different than they are now. When the Marsh was functionally intact as a tidal marsh system, so were other ecosystems throughout the western Americas. Connectivity between the Marsh and places such as Sierra Nevada streams, distant migratory bird nesting grounds, and adjacent grasslands allowed it to support immense numbers of migratory and resident animals, as well as a large human population.

Beginning in the late 1800s, hydrologic infrastructure, created to keep tidal water from encroaching on farmlands and duck clubs, significantly modified the appearance and functions of the marsh plain and sloughs. The addition of large quantities of sediment from hydraulic mining further affected the shape of the Marsh. Many natural landscape features and processes have been obscured by dikes, upstream dams and diversions, constructed wetlands, salinity control structures, roads and railroads. The cumulative effects of the introduction of approximately 7,000 dams and diversions upstream in the Sacramento and San Joaquin River watersheds (CALFED 1996), in particular, have dramatically altered the timing and volume of freshwater inflows. Subsidence as the result of wetland management for duck hunting is a problem in Suisun Marsh, although it is often overlooked because loss of elevation is not as extreme as in the Delta and because management objectives are different. Today, about 90% of the marsh plain has been diked (DWR 2010). This prevents tidal inundation and thus sediment delivery, except in the case of dikes overtopping during major floods or exceptionally high tides. Pond management can leave peaty soils exposed to atmospheric oxygen, causing them to decompose and become compacted. Under these conditions, soil-building processes slow down or are reversed. In concert, these physical changes have had major impacts on landscape form, sediment delivery, hydrologic circulation and soil formation in the Marsh.

Understanding how Suisun Marsh has changed with climatic variability and human management over the past 6,000 years provides insights as how to guide change in the future. Increasing hydrologic connectivity to counteract subsidence has a much better chance of succeeding in Suisun Marsh than in much of the Delta, which has far greater levels of subsidence with which to contend. The Marsh will continue to change and will likely play an increasingly important role in the conservation of the biota of the San Francisco Estuary and surrounding region.

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Chapter 3

Visualizing biogeographic data with animated maps:

A new look at the fishes of Suisun Marsh

Abstract

Since 1979, UC Davis researchers have collected data monthly for the Suisun Marsh Fish and Invertebrate Study, a project initiated by Professor Peter Moyle. This long-term study of fishes and invertebrates has yielded an enormous amount of interrelated data. Though the dataset has been analyzed with a variety of approaches over the years, many newer tools in data visualization have yet to be applied. One promising approach for exploring and communicating this dataset is with animated maps, which allow viewers to quickly and easily familiarize themselves with changes through time and in space. The animated maps created as a part of this study demonstrate the dynamic nature of the Suisun Marsh species assemblage, the importance of this dataset in understanding estuarine fishes, and the potential of newer software tools for communicating biogeographic information.

Introduction

Suisun Marsh is a 470 km^2 wetland in the San Francisco Estuary (figure 3.1). The Marsh is situated between the saline San Pablo Bay and the freshwater Sacramento-San Joaquin Delta (the Delta), and Suisun's water quality is characterized by variable salinity, regulated primarily by the volume of fresh water flowing through the Delta. Although about 80% of the marsh plain area is diked (SFEI 2012) and managed for waterfowl, it has undergone far less human

Figure 3.1. Suisun Marsh place names and notable features (CalAtlas 2012; Gesch *et al.* 2002; GreenInfo Network 2013; SFEI 2012).

modification in the past 150 years than most wetlands in the region. The Marsh offers a rich network of interwoven sloughs that support connectivity among aquatic habitat types with diverse characteristics (e.g., marine, brackish, relatively fresh, variable, stable, intertidal, deep water), and have varying levels of nutrient transport and production of food for fishes.

Researchers involved in the Suisun Marsh Fish and Invertebrate Study have recorded monthly counts of the fishes and aquatic invertebrates of Suisun Marsh since 1979 at over 20 field stations throughout the Marsh, generating a wealth of biogeographical information. With over 8,000 samples and hundreds of thousands of fishes measured, this is now one of the best datasets available for fishes in an estuarine environment. Exploration and communication of this dataset has thus far been limited, in part, by the same things that make it so tantalizing: its complexity and massive number of records. Finding the best way to visualize data can be challenging - and time-consuming - but is also critically important. Valuable long-term datasets such as this are good candidates for the application of advances in methodology.

The data have previously been analyzed and summarized, but have not yet been visualized spatially. For a dataset that is inherently spatial and temporal, time-enabled maps can improve our understanding of the data and help communicate it to non-specialists. From a geographic perspective, these maps (attached as supplemental appendices) are essentially time-lapse movies of fish and invertebrate responses to environmental pressures. Thus this study in landscape change geography provides a rare perspective on ecosystem change through time and in space. This research furthers our understanding of the fishes of Suisun Marsh and demonstrates the utility of mapping software for visualizing biogeographic data.

Biogeography of Suisun Marsh fishes

The intermediate position of Suisun Marsh, between San Pablo Bay and the Sacramento-San Joaquin Delta in the San Francisco Bay Estuary, is associated with wide variability in salinity, attracting both salinity-tolerant (euryhaline) freshwater and marine species thus supporting high species diversity (O'Rear 2014). Migratory fishes such as Chinook salmon (*Oncorhynchus tshawytscha*), striped bass (*Morone saxatilis*), and sturgeon (*Acipenser* spp.) also pass through the Marsh to forage. Suisun Marsh is a nursery for many fish species, such as splittail (*Pogonichthys macrolepidotus*), striped bass, and tule perch (*Hysterocarpus traskii*). Thirty-three fishes are considered common to the Marsh, with over 100 individuals caught between 1979 and 2012. Of these, 16 are native and 27 are classified as resident (appendix 1). In all, 58 fish species were caught between 1979 and 2012.

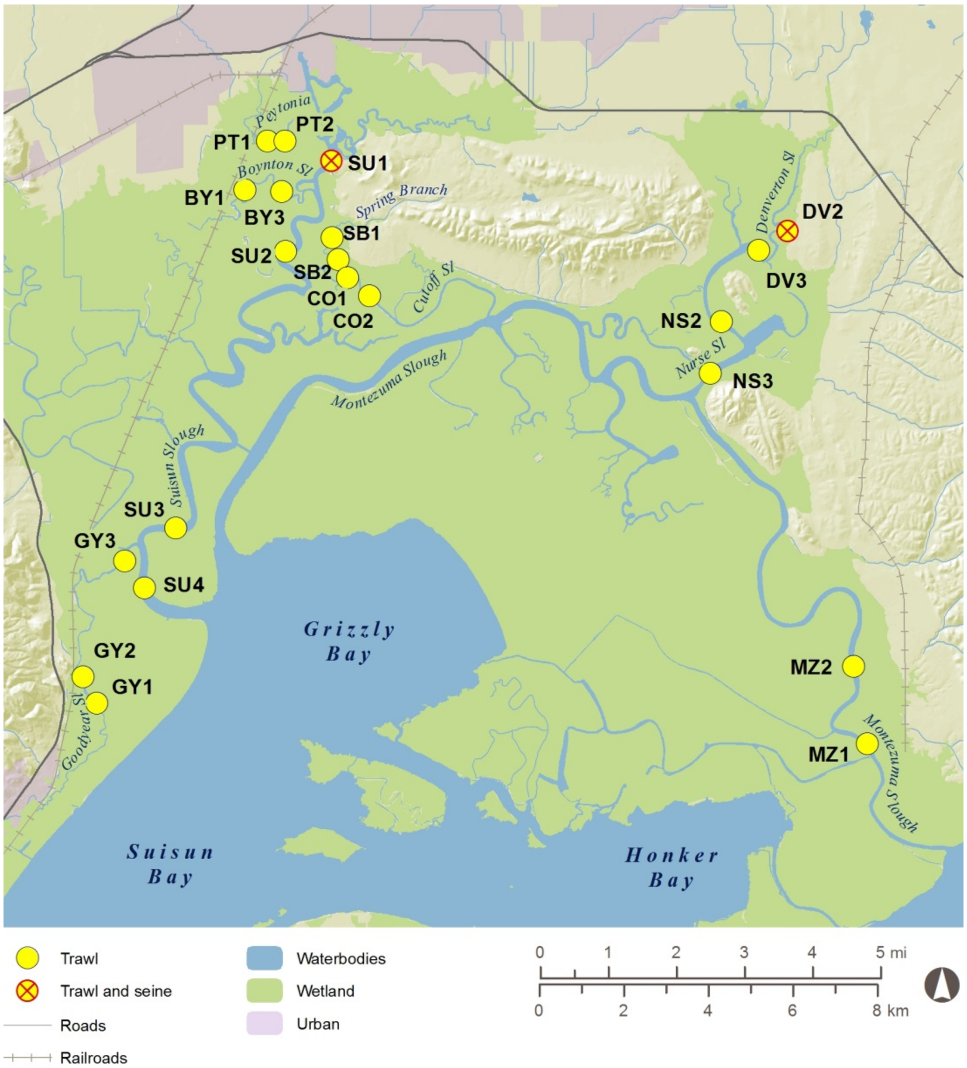
Many factors affect fish populations, making it difficult to isolate correlations between variables (Mount *et al.* 2012). Over the duration of the study, conditions likely influencing fish populations in significant ways include precipitation patterns, Delta water operations, Suisun Marsh salinity control gate operations, water quality conditions, alien species invasions, predator-prey interactions, habitat alteration, habitat restoration, and hydrologic management practices related to duck ponds, wastewater treatment facilities, and shifting environmental policies. Furthermore, marine conditions affect anadromous fish populations. Variation in habitat quality also exists within the marsh at hourly (tidal) and greater temporal scales and at numerous spatial scales (see chapter 1).

Untangling the population trends of Suisun Marsh's fishes and their likely drivers is therefore no simple exercise. Marsh-wide trends apparent in the Suisun Marsh dataset have been analyzed for connections to major drivers such as drought conditions, floods, operation of the salinity control gates, and alien species invasions (Matern *et al.* 2002; Meng *et al.* 1994; O'Rear and Moyle 2011), and differences in diversity and abundance related to slough types have been explored using non-spatial statistical methods (Matern *et al.* 2002). Project annual reports submitted to the California Department of Water Resources have briefly explored Marsh-wide population variability for individual species (O'Rear and Moyle 2009; O'Rear and Moyle 2010; O'Rear and Moyle 2011), and in-depth studies have been completed for white catfish (*Ameiurus catus*) (O'Rear 2012) and splittail (Daniels and Moyle 1983; Moyle *et al.* 2004). Overall, the fish and also the invertebrate assemblage in Suisun Marsh is driven by environmental conditions and invasions, and abundance appears to respond to favorable reproductive conditions. Perhaps the biggest unknown is the effect of duck club management of ponded areas on the marsh plain; it is possible that management strategies are both bolstering fish populations by providing additional rearing and nursery habitat and occasionally having locally catastrophic effects when water with extremely low dissolved oxygen is released into adjacent sloughs, causing fish kills (O'Rear and Moyle 2011).

Methods

Study data

Samples of fishes and invertebrates have been collected monthly with otter trawls and beach seines between May 1979 and December 2012 (Meng *et al.* 1994; O'Rear and Moyle 2011). These methods are primarily intended to sample fishes, and species and count data for invertebrates that happen to be caught are also recorded. Over the course of the study, over 48



Code	Site name
BY1	Boynton 1
BY3	Boynton 3
CO1	Cutoff 1
CO2	Cutoff 2
DV2	Denverton 2
DV3	Denverton 3
GY1	Goodyear 1
GY2	Goodyear 2
GY3	Goodyear 3
MZ1	Montezuma 1
MZ2	Montezuma 2
NS2	Nurse 2
NS3	Nurse 3
PT1	Peytonia 1
PT2	Peytonia 2
SB1	Spring Branch 1
SB2	Spring Branch 2
SU1	Suisun 1
SU2	Suisun 2
SU3	Suisun 3
SU4	Suisun 4

Figure 3.2. Suisun Marsh Fish and Invertebrate Study regular sample sites 1979 - 2012 (CalAtlas 2012; Gesch et al. 2002; San Francisco Estuary Institute and (SFEI) 2012).

sites have been established in Suisun Marsh, but only 21 have been regularly sampled on an ongoing basis (figure 3.2). Of these, the four sites in Nurse and Denverton sloughs were not regularly sampled until May 1994. Sampling efforts prior to 1980 were inconsistent, so they are not included in map animations. Both trawl and beach seine data are collected at two sites and, to keep information presented to the viewer consistent, seine data are not included in animations. Thus animated maps show data collected with trawls at 21 sites from 1980 to 2013.

Water quality parameters have been recorded as a part of the Suisun Marsh Study, however dates of record vary (table 3.1).

Table 3.1. Dates of record for water quality parameters collected as part of the Suisun Marsh Fish and Invertebrate study.

Parameter	Date of record
Temperature	January 1980 - present
Salinity (ppt)	January 1980 - present
Specific conductivity	March 1985 - present
Dissolved oxygen	January 2000 - present
Percent saturation	May 2000 - present
Secchi depth	January 1980 - present

Data collected in the field are stored in a Microsoft Access 2013 database where Standard Query Language (SQL) can be used to query data and records can be exported for use in other applications. Two tables were added to the database; one to enable year-class designations (“AgesBySizeMo”) and a second to allow preparation of records for spatial display (“UCD_Fish_SampleSites_fullTable”). These tables are attached as supplemental appendices.

Ancillary data for outflow from the Delta at Collinsville station is available through the California Department of Water Resources’ (DWR) data clearinghouse: the California Data Exchange Center (CDEC) (DWR 2013). An operations schedule for the Suisun Marsh Salinity Control Gates is also available through DWR at their Suisun Marsh website (DWR 2014).

Year classes

To meaningfully map fish populations by month, it was necessary to first determine year classes for species with suitable data before creating maps. Fishes that live at least several years and that grow to moderate or large sizes, such as splittail, striped bass, and tule perch, go through a series of functional roles in the environment as they grow. Thus breaking data by year-class helps show how abundance and distribution that may be related to rearing and migration. When delineating year-classes, more data allows a more robust analysis, so data used in generating year classes were drawn from all records where fish standard length was greater than 0 (unmeasured fish are entered as 0 standard length), at all 48 sites sampled between the inception of the study in 1979 and December 2012, and with all methods including otter trawls, mid-water trawls, and beach seines.

Pivot tables were used to summarize species by month caught and sort by standard length (appendix 2), and then length frequency histograms were constructed to assist identification of year-class breaks (appendix 3). In the resulting year-class table, the minimum length for young-of-the-year ("Age-0") fish of species with year classes was set to 1 mm to exclude records where 0 mm was recorded as fish standard length; including these zeroes would have introduced error in map representations of young-of-the-year fishes. A detailed account of year-class delineation workflow is included in appendix 4.

Preparing data for map animations

After determining year-class categories for fishes, year-class information was added to the main Microsoft Access database as a table. Where tow duration was recorded as "zero" and catches of fish were recorded , tow duration was filled with the standard duration for tows in that slough (10 minutes for Suisun and Montezuma sloughs, 5 minutes for smaller sloughs) to support catch per unit effort (CPUE) calculations.

A series of queries generating data tables with fields required to map fishes, including CPUE as fish-per-hour, were prepared in Access. A column was added to store altered dates, where the "day" field for all sample dates was converted to "01" (first day of the month), as monthly animations on ArcMap require the same day number for sequential display. On occasions where more than one trawl was towed at a given site in a given month and the same species were caught in multiple trawls, this altered date field allowed catch to be summed by month. Prepared catch records for all species were then moved into the ESRI ArcMap mapping environment as a single file and located in space according to latitude/ longitude values stored in the table. A complete account of the steps involved in preparing data for animations can be found in appendix 5.

Water quality

Water quality parameters recorded in the Suisun Marsh study include temperature, salinity (ppt), specific conductivity, dissolved oxygen, percent saturation, and Secchi depth. If more than one measurement was taken at a given site on a given day, values were averaged. Outliers were identified and resolved by reviewing original data sheets. Date formatting was done as described above. In ArcMap, latitude and longitude values included in the table were used to support a spatial join with polygons representing sections of sloughs around the point sample locations.

Suisun Marsh Salinity Control Gate operation effects on salinity

Salinity Marsh Salinity Control Gate (SMSCG) operation data were converted to a metric representing their effect on salinity based on the relationship between operations and upstream and downstream salinity as recorded at California Department of Water Resources monitoring stations. This method was devised by Steven Micko and is explained in appendix 6.

Mapping and cartography

In ArcMap, catch records for individual species and species year classes (when applicable) were exported from the master file containing data for all species to separate files to allow unique display settings. For each species, CPUE was displayed as a circle sized according to quantity, with larger circles represent larger catches. For species with year-class breaks, colors were tinted according to the year-class of the fish being represented, with lighter tints for younger fish.

Water quality parameters were represented with gradients of color ranging from reds (warmest/ saltiest/ lowest dissolved oxygen/ least Secchi depth) to yellows (mid-range) to blues (coldest/ freshest/ highest dissolved oxygen/ highest Secchi depth). Salinity control gate effects on flow are represented in maps with a chevron shape sized according to the relative effect they have on salinity (appendix 6).

Sample sites depicted in maps include only the 21 sites where long-term continuous monitoring has occurred (figure 3.2). Small dots represent sampling stations on maps. When no monthly sample was taken at a site an “x” is placed at the site location. Gaps in water quality data are self-evident because the background polygon color shows through. A single frame from an animation is included here as an example (figure 3.3).

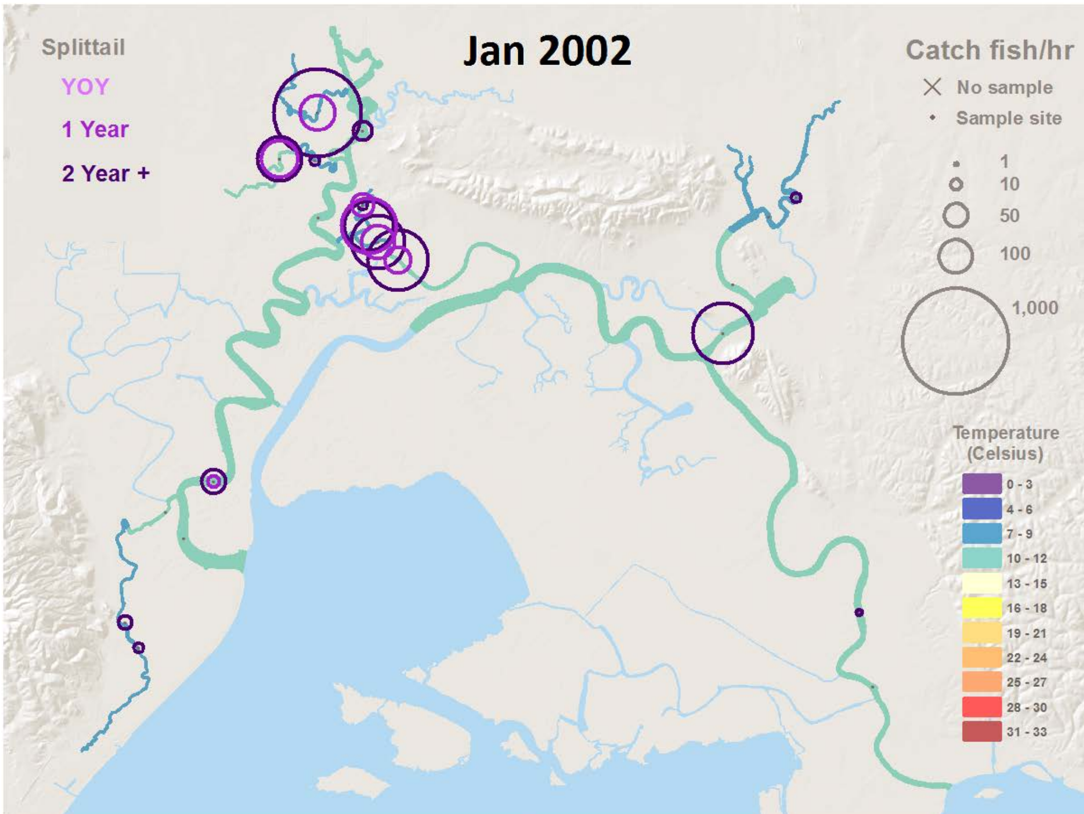


Figure 3.3. Map animation frame showing CPUE for three year-classes of splittail and water temperature.

Animation

In ArcMap, a base map was set up, time was enabled for species, water quality, salinity control gate operations, and Delta outflow layers, and data were explored via animation. After determining data combinations and temporal extents of interest, animation frames were exported to JPEG images. These JPEGS were compiled in the Microsoft Movie Maker environment and saved as MPEG-4 video files. Animations are included here as Supplemental Materials.

Results

Year classes

Of the 33 species common to Suisun Marsh, it was possible to delineate preliminary year classes for 14 species at the time of this analysis (appendix 4). For the other 19 common species, data does not show a clear enough signal to support classification. When strong signals were present in the data, it was possible to observe year classes even with relatively few records, as with starry flounder (*Platichthys stellatus*). Factors preventing the delineation of year classes for remaining species include; (1) insufficient records in the dataset, (2) species do not occur in sample locations as juveniles, (3) year classes are obscured by multiple rearing events within years, as with Sacramento sucker (*Catostomus occidentalis*), (4) fish have lifespans of about one year, causing year-class information to have limited value and also precluding juveniles from being caught due to sample methods, as with threadfin shad (*Dorosoma petenense*). All year-class information presented here should be considered preliminary until it can be verified with otolith or scale studies.

Year classes had previously been determined for splittail (Daniels and Moyle 1983; Sommer and Matern 1999) and white catfish (O'Rear 2012). Year classes for these two species were revised in this analysis because new data were available, which led to class breaks changing slightly for both species.

Animations - data exploration

Map layers containing information on distribution and abundance of common fish and invertebrate species for each month from January 1980 to December 2012 were used for data exploration. Water quality parameters and ancillary data including Suisun Marsh Salinity Control Gate operations were included in data exploration as well.

In preliminary presentations of the animations, new questions were quickly generated among the Suisun Marsh Fish and Invertebrate Study working group. The potential of this method as in interactive product was readily apparent, as participants were immediately engaged and jumped at the chance to direct which data layers might be shown together to inform various hypotheses. Participants were also immediately interested in applying the method to data collected at other locations.

Animations - output

From these sources, movie files of animated maps were generated. Three movies are included here as supplemental materials to demonstrate the range of applications. These include (1) splittail of all year-classes with water temperature 1980 - 2012, (2) striped bass of all year-classes with water temperature 1980 - 2012, (3) splittail and striped bass young-of-the-year with water temperature, June through October 1980 - 2012, and (4) overbite clam (*Potamocorbula amurensis*), salinity, and SMSCG operations 1989 -2012.

In presentations at the American Fisheries Society 2014 annual meeting and a special DWR symposium in June 2014, it was clear that representing these interrelated data simultaneously in map animations allowed viewers to quickly and easily comprehend this large dataset and to familiarize themselves with changes through time and in space in the estuary.

Main findings

The animations created for this study show changes through time and in space, demonstrating the dynamic nature of Suisun Marsh species. Animations are useful for expert-level data exploration and for communicating to diverse audiences about the ecology of Suisun Marsh. More generally, map animations are a powerful exploratory tool and communication method for long-term biogeographic datasets, offering an intuitive format and user-friendly interface. This method is an exciting way to work with biogeographic data and to understand environmental change, especially for datasets with numerous sample sites and high temporal resolution.

Discussion

The primary goal of this study is to further our understanding of Suisun Marsh fishes. The secondary goal is to demonstrate the utility of new tools for visualizing biogeographic data. In the course of pursuing these objectives, year classes for 14 species common to Suisun Marsh were assessed. All three topics are discussed below.

Better understanding of Suisun Marsh fishes

The complexity of ecological relationships is a challenge for those attempting to collect and transform raw data on organisms and their environment into usable information. Animated maps of Suisun Marsh fishes succeed in presenting data in a format that allows for simultaneous user comprehension of temporal and spatial dynamics that are otherwise only arrived at through long and careful study. When exploring data through map animations, one can instantly combine species and background map features, enabling users to query the database and combine information in new and helpful ways. While map animations do not provide defensible analytic results, they point to potentially important questions and can serve as tools to communicate findings of in-depth studies to a non-specialist audience.

Map animations presented here are aimed at an informed audience already familiar with fish ecology, especially in the San Francisco Bay Estuary. For this audience, these maps allow immediate insights into the data. Population response most likely related to Delta outflow, for example, is noticeable in the late 1980s when splittail populations dip due to drought then rebound in the late 1990s after outflow increases (supplemental materials 1a). An annual temporal rhythm related to their reproductive cycles is seen in striped bass, which live primarily in marine and estuarine waters as adults and use the Marsh as a nursery, with adults appearing in the spring followed by young-of-the-year in summer (supplemental materials 1b; appendix 3).

In comparing spatial distributions and abundance of splittail and striped bass young-of-the-year, animations make it easy to see that these species overlap temporally and spatially, with striped bass producing overall higher numbers of offspring (supplemental materials 1c). The temporal overlap in reproductive timing of splittail and striped bass can also be seen in length frequency histograms (appendix 3). In the fourth animation, viewing young-of-the-year of a variety of species illustrates Suisun Marsh's role as a nursery for a diverse species assemblage (supplemental materials 1d). Splittail and striped bass are excluded from this animation because their large numbers would make the display more difficult to understand.

In viewing white catfish and dissolved oxygen (period of record begins January 2000), these fish are seen to occur occasionally in low numbers for most of the study period, with catch increasing slightly in the mid-1990s and again around the year 2000 (supplemental materials 1e).

In the final animation, Asian clam (*Corbicula fluminea*), salinity, and SMSCG operations are viewed together. Asian clams, while numerous, are somewhat limited in spatial and temporal distribution (although sampling methods are not designed to catch clams) with the highest catches generally being in lower Suisun Slough. Salinity varies in spatially predictable ways, being controlled by freshwater discharge from the Delta, discharge from the Suisun Slough drainage, and other smaller drainages and wastewater releases from the Fairfield-Suisun Wastewater Treatment District. Timing of winter rains is apparent, with the marsh becoming saltiest when rains arrive late. Effects of SMSCG operations are difficult to discern, likely because they have been aggregated to the monthly scale (supplemental materials 1f).

Visualizing biogeographic data with animated maps

For large biogeographic datasets with well-resolved temporal sampling, animations can be a valuable tool. One might imagine similar animations for state-wide butterfly populations or Audubon Christmas bird counts. Animations can also show migration paths or movements in response to stimuli, so working with a variety of tracking data is possible.

Many possibilities exist for abiotic data as well. For example, salinity data from Delta and Suisun compliance stations could be animated in conjunction with salinity control gate operations at daily resolution to communicate effects of the gates.

Concerns and cautions

Just as statistical analyses typically omit spatial and/or temporal information in presentation of results, tradeoffs are made when presenting these data cartographically. These maps are intended to point to promising areas for further analysis and do not include any formal statistical analysis. Therefore assigning causality after viewing apparent correlations or patterns in the data should be resisted. On the other hand, animations can help in developing hypotheses for statistical testing and can be employed to communicate results of analyses already performed or environmental relationships that are well-established, such as life history-related species movements.

Representing relative quantities with circles is not ideal because the exact relationship between circle sizes and quantity is not easy for the viewer to judge accurately (Cleveland *et al.* 1982). Yet alternatives such as dynamic bar charts located in space or chloropleth maps have their own shortfalls. Viewing dozens of dynamic bar charts at one time would clearly overwhelm the viewer, while chloropleth mapping would require polygon representation of data that are associated with points, would add confusion due to additional color variation, and would obscure underlying map layers such as water quality.

Species year classes

Year classes for 14 species were delineated using catch data, which demonstrates that these species are using Suisun Marsh as a nursery. Sample sizes for year classes range from hundreds to tens of thousands of fish caught. The kind of long-term intensive sampling that generated the Suisun Marsh dataset is rare, and that life history details are borne out simply by length and date records is remarkable. This is one of many reasons why long-term datasets such as this are valuable.

Length frequency histograms (appendix 3) show that some species reside in the Marsh throughout their lives [splittail, tule perch, common carp (*Cyprinus carpio*)] while others only inhabit the Marsh occasionally as adults [striped bass, starry flounder, American shad (*Alosa sapidissima*)]. Length frequency histograms also reveal interesting life-history traits of species that could not be delineated into year classes. For example, Sacramento suckers spawn opportunistically in response to environmental conditions for a period of about a month in any given year, between February and May (Moyle 2002). Thus, even with a relatively large sample size (n = 3,395), year classes are obscured by the erratic appearance of and growth of juveniles (appendix 3).

Conclusions and next steps

Animated maps underscore the importance of this dataset in understanding estuarine fishes and make its contents more accessible to specialists and non-specialists alike. Animations help visualize suspected relationships among factors and can point to promising research topics. Correlations that have been demonstrated statistically can be communicated with animations, making scientific findings more accessible to non-specialists. Year-class information contributes to our understanding of how fishes use Suisun Marsh habitat.

There are further possibilities for exploring the Suisun Marsh dataset. For example, derivatives of Suisun Marsh study data, such as diversity indices, native vs. alien young-of-the-year catches, and groupings based on life-history strategies could be presented in map animations.

Translating these products for presentation to a general audience would require further attention to the final product, perhaps including interactive map components and explanatory text or voice-overs. Solicitation of feedback from non-specialists to inform approaches to communicating the content of the data would be a critical step in the refinement process.

Appendix 1
Common fishes and invertebrates of Suisun Marsh ordered by catch 1979 - 2012

Common Name	Scientific Name	Code	Catch	Origin	Status	Year Classes
Striped bass	*Morone saxatilis*	SB	105,755	Alien	Resident	*
Inland silverside	*Menidia beryllina*	ISS	78,566	Alien	Resident	
Yellowfin goby	*Acanthogobius flavimanus*	YFG	35,256	Alien	Resident	
Splittail	*Pogonichthys macrolepidotus*	ST	29,518	Native	Resident	*
Threespine stickleback	*Gasterosteus aculeatus*	STBK	22,741	Native	Resident	
Tule perch	*Hysterocarpus traskii*	TP	20,682	Native	Resident	*
Longfin smelt	*Spirinchus thaleichthys*	LFS	13,053	Native	Resident	*
Shimofuri goby	*Tridentiger bifasciatus*	SG	12,018	Alien	Resident	*
Prickly sculpin	*Cottus asper*	SCP	11,363	Native	Resident	*
Threadfin shad	*Dorosoma petenense*	TFS	7,863	Alien	Resident	
Pacific staghorn sculpin	*Leptocottus armatus*	STAG	5,831	Native	Resident	
Common carp	*Cyprinus carpio*	CP	5,516	Alien	Resident	*
White catfish	*Ameiurus catus*	WCF	5,454	Alien	-	*
Sacramento sucker	*Catostomus occidentalis*	SKR	3,667	Native	Resident	*
Starry flounder	*Platichthys stellatus*	SF	2,248	Native	Resident	*
Delta smelt	*Hypomesus transpacificus*	DS	1,936	Native	Resident	*
Black crappie	*Pomoxis nigromaculatus*	BC	1,913	Alien	Resident	*
American shad	*Alosa sapidissima*	ASH	1,372	Alien	-	*
Black bullhead	*Ameiurus melas*	BLB	876	Alien	-	
Shokihaze goby	*Tridentiger barbatus*	SKG	717	Alien	Resident	*
Pacific herring	*Clupea pallasi*	PH	563	Native	-	
Northern anchovy	*Engraulis mordax*	NAC	533	Native	Resident	
Chinook salmon	*Oncorhynchus tshawytscha*	CS	470	Native	Resident	
Western mosquitofish	*Gambusia affinis*	MQF	383	Alien	Resident	
Sacramento pikeminnow	*Ptychocheilus grandis*	SPM	373	Native	Resident	
Goldfish	*Carassius auratus*	GF	361	Alien	Resident	*
Channel catfish	*Ictalurus punctatus*	CCF	181	Alien	-	
Sacramento blackfish	*Orthodon microlepidotus*	BF	142	Native	Resident	
Hitch	*Lavinia exilicauda*	HCH	136	Native	Resident	
Rainwater killifish	*Lucania parva*	RWK	126	Alien	Resident	
White sturgeon	*Acipenser transmontanus*	WS	115	Native	Resident	
White crappie	*Pomoxis annularis*	WC	112	Alien	-	
Wakasagi	*Hypomesus nipponensis*	WAK	106	Alien	Resident	

Macroinvertebrates

Common Name	Scientific Name	Code	Catch	Origin	Status	Class
California bay shrimp	*Crangon franciscorum*	CRANGON	252,169	Native	Resident	Crustacea
Overbite clam	*Corbula amurenis*	CORBULA	250,550	Alien	-	Bivalvia
Siberian prawn	*Exopalaemon modestus*	EXOPAL	78,201	Alien	Resident	Crustacea
Black Sea jellyfish	*Maeotias inexpectata*	MAEOTIAS	59,902	Alien	-	Hydrozoa
Korean grass shrimp	*Palaemon macrodactylum*	PALAEMON	35,833	Alien	Resident	Crustacea
Opossum shrimp	*Neomysis* sp.	MYSIDS	10,863	Native	Resident	Crustacea
Asian clam	*Corbicula fluminea*	CORBICULA	5,871	Alien	Resident	Bivalvia
Harris mud crab	*Rithroponopeus Harrisi*	HARISSMC	380	Native	Resident	Crustacea

Appendix 2
Year-class pivot tables

American shad Suisun

Month 1979-2012

Sum of Count													
Std Length	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**Grand Total**
<1		0					5	0			0	4	9
6-10							2						2
16-20							2	7					9
21-25				2		2	23	9	1				37
26-30				37	4	1	79	4	1				126
31-35				21	3	1	37	1					63
36-40						1	12	2					15
41-45				1			3	1	2	1			8
46-50	1						1	4	2				8
51-55	1						3	8	3	2			17
56-60			1					9	23	7			40
61-65							4	7	27	13	5	4	60
66-70							4	20	35	25	9	12	105
71-75	3	1	1					26	47	24	16	32	150
76-80	3	1	1					22	31	24	24	42	148
81-85	4	1	1	1				10	32	19	17	36	121
86-90	3	6	2	1				6	13	25	17	25	98
91-95	6	1	5	4				2	13	9	31	13	84
96-100	5	1	2	2				2	6	8	37	7	70
101-105	2		2	8	1	1		1	2	12	23	5	57
106-110	2	1	1	4					6		10	1	25
111-115	2			4	1	1				1	16	3	28
116-120	6	1	1	5					2		2	2	19
121-125	1			2	1				1		8	1	14
126-130	2		1	3	3	1			1			1	12
131-135				2	1	1	1		1				6
136-140	1										1		2
141-145							3				1		4
146-150							1				1		2
151-155					1				2		3	2	8
156-160				1			2		1		1	2	7
161-165											1		1
166-170						1	1					1	3
171-175	1									1	1		3
181-185		1											1
186-190		1			1								2
191-195												1	1
196-200											1		1
201-205												1	1
206-210	1										1	1	3
221-225												1	1
351-355							1						1
Grand Total	**44**	**15**	**18**	**98**	**16**	**10**	**184**	**141**	**252**	**171**	**226**	**197**	**1372**

Splittail 1979-2012

Month Suisun

Sum of Count Std Length	1	2	3	4	5	6	7	8	9	10	11	12	Grand Total
<1	82	82	52	165	160	193	507	70	2		6	34	1353
1-5			1										1
6-10	1												1
11-15					1		2						3
16-20					14	1	1						16
21-25		4		3	51	25	3	2					88
26-30		1		3	85	59	21						169
31-35					68	93	63						224
36-40					46	172	31	4					253
41-45	1			1	13	254	71	7	2			1	350
46-50		1		1	8	302	141	20					473
51-55		1		1	3	282	206	44	3		2	1	543
56-60	2					163	288	69	11	2		5	540
61-65	5	2	1	2		89	316	125	38	11	8	7	604
66-70	11	17	5	2		27	276	194	81	32	18	13	676
71-75	49	28	9	5		5	263	208	126	61	28	37	819
76-80	84	46	19	15	3	2	197	192	135	97	49	54	893
81-85	133	79	33	24	5		114	149	147	87	84	112	967
86-90	146	90	51	45	10		41	117	125	80	91	124	920
91-95	145	124	78	65	19	3	8	93	118	77	94	155	979
96-100	163	122	92	107	56	5	2	58	71	64	77	161	978
101-105	148	102	90	149	59	13	2	24	76	68	96	109	936
106-110	149	117	126	184	103	21	8	4	47	61	73	118	1011
111-115	165	81	119	226	114	52	14	6	23	37	49	94	980
116-120	100	72	131	228	164	70	10	10	9	17	30	67	908
121-125	61	44	113	203	210	130	33	15	5	7	23	37	881
126-130	38	22	65	218	244	116	33	21	5	7	10	27	806
131-135	25	21	53	139	273	145	61	26	4	2	8	13	770
136-140	16	12	25	75	217	151	43	31	7	9	8	12	606
141-145	10	12	18	47	160	168	78	28	15	12	13	31	592
146-150	24	24	16	23	105	152	94	33	12	8	15	31	537
151-155	34	42	15	32	62	142	123	69	38	23	26	44	650
156-160	62	31	17	22	40	99	138	91	46	21	32	54	653
161-165	72	46	22	30	22	51	137	97	57	33	46	62	675
166-170	79	49	37	36	25	36	117	104	65	36	43	57	684
171-175	85	67	51	70	28	21	70	328	71	46	57	72	966
176-180	88	58	61	60	34	14	58	60	60	29	46	56	624
181-185	77	37	56	86	40	26	36	46	48	34	50	65	601
186-190	72	35	52	76	37	31	25	26	38	18	53	49	512

191-195	63	43	42	66	52	46	29	26	21	18	36	31	473
196-200	56	27	43	58	52	31	35	23	22	13	34	38	432
201-205	33	19	33	43	59	54	47	29	25	13	24	37	416
206-210	39	27	31	45	49	46	35	41	25	15	26	27	406
211-215	44	12	26	46	35	38	40	38	30	16	29	29	383
216-220	43	16	10	29	33	29	37	39	25	10	17	31	319
221-225	56	13	12	27	24	35	34	36	25	11	17	36	326
226-230	30	12	11	15	23	25	27	26	41	14	29	27	280
231-235	29	20	7	17	21	20	29	22	22	17	18	34	256
236-240	20	20	7	9	17	16	32	14	23	6	23	23	210
241-245	25	22	5	13	8	13	15	34	12	11	24	26	208
246-250	20	12	9	9	12	16	18	20	11	7	14	23	171
251-255	26	9	10	12	2	15	10	17	9	8	21	29	168
256-260	16	10	4	15	10	10	12	12	9	19	12	12	141
261-265	24	12	6	9	7	12	10	11	11	13	20	33	168
266-270	23	15	2	6	5	6	15	9	9	8	13	28	139
271-275	13	9	2	6	4	8	8	11	9	12	15	29	126
276-280	20	8	3	8	3	8	4	6	5	10	6	18	99
281-285	14	5	1	6	15	4	7	6	5	11	17	18	109
286-290	9	5	3	2	4	5	5	7	8	2	7	21	78
291-295	12	11	6	6	5	3	3	10	6	5	9	11	87
296-300	8	3	2	4	3	3	5	3	2	6	8	12	59
301-305	10	6	2	1	4	7	3	3	1	5	5	6	53
306-310	8	3	3	1	3	4	2	4	1	4	4	5	42
311-315	7	3	3	2		1	2	4		7	3	5	37
316-320	4	4			2	1	1	2	3	1	2	10	30
321-325	5	2			2		2		1	5	3	3	23
326-330	2	1		1	2					1	1	3	11
331-335	2			1				1	1	2		2	9
336-340	2					1		2			1	1	7
341-345								2				2	4
346-350			2										2
351-355												1	1
356-360		1											1
371-375											1		1
471-475								1					1
Grand Total	**2790**	**1819**	**1693**	**2800**	**2935**	**3570**	**4098**	**2830**	**1847**	**1249**	**1574**	**2313**	**29518**

Goldfish Suisun

Month 1979-2012

Sum of Count													
Std Length	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**Grand Total**
21-30					6								6
31-40					3	2							5
41-50					3	2							5
51-60	1				1	8					5	1	16
61-70						8	2		1		6	1	18
71-80	1					4	3				1		9
81-90	1				1	2	2	2	1	1		4	14
91-100	1			3			1	2			4	7	18
101-110	4		2	1				2	2	1	5	26	43
111-120	5	3	4	3				1	4	2	8	23	53
121-130	3	2	1	2	1	1			5	2	4	8	29
131-140	3	1	1	2		2					3	3	15
141-150	1	3	1	1	3	1	1			1			12
151-160	1	1	2		1	1				1			7
161-170		2	1	1	1		1	1				1	8
171-180	2			1			2						5
181-190		2		1	1		2		1		1	1	9
191-200	3			2						1			6
201-210	4		1	1			1	1	1		1	2	12
211-220	4		3	1	1		1						10
221-230	4	1		4				1	1				11
231-240	1				2		2					2	7
241-250		1		2			1			1			5
251-260	2	1		1	1		1				1		7
261-270	1	2		2	1	1	1					1	9
271-280	2		1	1	1	4			1		1		11
281-290	1				1								2
291-300				1							1		2
311-320	1	1					1						3
321-330					1	1							2
331-340	1												1
371-380						1							1
Grand Total	**47**	**20**	**17**	**30**	**29**	**38**	**22**	**10**	**17**	**10**	**41**	**80**	**361**

Common carp 1979-2012

Month Suisun

Sum of Count Std Length	1	2	3	4	5	6	7	8	9	10	11	12	Grand Total
<1	17		32	50	45	37		1	2				184
8-14					4								4
15-21				4	67	6	2						79
22-28				11	94	9	26	5					145
29-35	1			9	65	12	16	4					107
36-42					20	23	19	13					75
43-49					9	20	16	5	1	1			52
50-56					1	28	15	5				1	50
57-63				1	6	9	45	3	1		2		67
64-70					1	16	44	5	1				67
71-77		1				15	45	25	1				87
78-84						12	45	35	3	3			98
85-91		1	1	1		9	36	42	5	3	1	2	101
92-98	1	2			1	6	26	35	8	4	8	1	92
99-105		1	1	1	1	6	13	34	11	12	4	2	86
106-112	3	2	1	2	1		18	30	14	8	4	7	90
113-119	2	1	2	3	2	1	17	38	10	8	17	7	108
120-126	5	3	8	8	4	2	10	32	22	18	11	16	139
127-133	6	3	2	7	2	3	11	20	26	17	17	20	134
134-140	3	3	4	9		3	1	22	25	20	14	18	122
141-147	5	1	6	11	3	3	4	12	13	19	16	17	110
148-154	7	7	4	12	4	2	2	16	11	11	16	17	109
155-161	2	4	7	14	6			5	8	11	15	13	85
162-168	5	5	5	15	2	3		5	12	10	17	14	93
169-175	2	6	7	16	5	1	1	4	5	10	7	14	78
176-182	5	2	9	8	8	6	2	1	2	7	7	9	66
183-189	2	5	6	16	8	7	4	4	2	4	2	6	66
190-196	4	5	5	14	11	3	4	3		6	7	6	68
197-203	4	5	9	19	4	1	5	1	1	2	4	4	59
204-210	3	3	7	12	8	5	4		3		7	15	67
211-217	7	3	3	11	7	9	2	1	1	1	5	8	58
218-224	1	1	6	10	6	6	2	1	3	2	3	6	47
225-231	7	4	2	9	8	14	5	2	2	4	3	15	75
232-238	3	3	6	6	7	10	3	4	2	2	7	14	67
239-245	1	4	1	6	5	6	7	4	1	1	3	13	52
246-252	2	6	5	4	5	5	3	2	1	1	3	12	49
253-259	4	3	2	3	2	6	5	4	2	3	5	7	46
260-266	10	6	1	9	5	4	1	3	3	5	8	8	63
267-273	4	7	9	6	10	1	7	3	2	2	3	13	67

274-280	12	3	7	7	4	5	5	2	4	2	2	13	66
281-287	5	2	8	7	5	3	3	3		1	7	8	52
288-294	9	3	6	10	5	4	1	6	4	2	3	5	58
295-301	7	7	7	14	8	3	6	1	5	2	2	9	71
302-308	2	5	7	7	5	4	1	6	1	1	2	4	45
309-315	7	6	9	5	8	7	4	3	3	2	2	5	61
316-322	10	12	6	5	6	2	7	3	2	2	1	6	62
323-329	9	1	6	7	10	3	3	3	1	3	2	3	51
330-336	4	4	9	12	9	6	7	4	4	5	5	6	75
337-343	8	5	7	6	8	4	2	2	2	2	2	4	52
344-350	9	9	10	11	10	5	5	3	3	7	5	5	82
351-357	2	2	12	5	7	3	5	4	1	4	5	5	55
358-364	13	5	12	9	7	2	4	6	5	2	5	5	75
365-371	6	14	12	7	10	9	6	6	2	4	8	10	94
372-378	7	1	6	4	4	2	2	8	3	2	2	6	47
379-385	14	14	15	18	17	3	5	6	5	9	5	8	119
386-392	11	11	8	9	10	7	4	3		2	6	3	74
393-399	5	3	4	10	3	3	6	2	5	2	1	7	51
400-406	14	12	11	16	13	8	4	2	5	6	7	6	104
407-413	6	7	13	16	8	2	3	2	6	5	4	9	81
414-420	6	13	8	14	13	8	5	6	8	3	6	8	98
421-427	5	3	7	7	9	4	3			2	3	2	45
428-434	7	8	13	7	4	6	1	5	3	1	5	4	64
435-441	11	12	8	17	12	7	3	3	6	1	3	11	94
442-448	1	5	7	2	5	3	4	1		1	2	2	33
449-455	12	12	7	5	6	9	4	4	3	6	5	8	81
456-462	5	10	5	3	5	4	3	3	2	5	6	5	56
463-469	1	1	2	5	3	4		1		2	1		20
470-476	4	10	10	9	8	4	1	2	3	4	4	9	68
477-483	8	4	5	1	8	6	1	2	2	1	5	5	48
484-490	5	7	5	7	4	4		3	3	1	2	3	44
491-497	2	5	1	4		3		1		3			19
498-504	7	10	7	3	4	8	1	2	4	4	2	5	57
505-511	3	9	6	6	7	3	2		4	2		6	48
512-518		1	1	1	1						1		5
519-525	6	5	3	3			2			2	1	4	26
526-532	2	1	2		2	1		1	1	1		1	12
533-539					1								1
540-546		3	3			2			1			1	10
547-553	6	2	2		2	2	1			1	2	4	22
554-560	2	6	1	1	4			1			1	2	18
568-574		2			3						2	3	10
575-581			1							1		2	4
589-595	1								1				2

596-602		4	2		1	1		2	1		1	3	15
603-609				1								1	2
610-616					1		1	1	1				4
617-623	1												1
624-630	3												3
638-644				1	1		1			1		1	5
645-651	2											3	5
659-665				1								1	2
666-672	1												1
680-686		1											1
694-700									1				1
715-721	1									1			2
743-750										1		1	2
Grand Total	**378**	**357**	**432**	**590**	**698**	**473**	**582**	**542**	**309**	**304**	**344**	**507**	**5516**

Sacramento sucker 1979-2012

Month Suisun

Sum of Count Std Length	1	2	3	4	5	6	7	8	9	10	11	12	Grand Total
<1		1	123	127	19	2							272
11-15					1								1
16-20				3			1						4
21-25				4	2		1						7
26-30			1	2	5	2							10
31-35	3	5		1	1								10
36-40	5	3	1	1	5	3							18
41-45	14	2	3	2	1	3	1		1			1	28
46-50	10	6	6	3	4	6	2			1		1	39
51-55	4	9	2	2	8	8	5					1	39
56-60	10	3	3	2	2	9	8			1		3	41
61-65	12	10	3	5	4	11	9	1				1	56
66-70	6	6	5	4	3	8	10	5	1			3	51
71-75	3	8	7	12	3	7	13	1	1			2	57
76-80	4	3	4	5	4	5	8	5		2		1	41
81-85	3	2	3	6	3	9	7	4	2	1	2	4	46
86-90	3	1	3	5	4	1	4	3	1	1		7	33
91-95	6	4	2	4	5	2	5	4	2			3	37
96-100	6	6	5	6	4	2	8	3	2	1	1	4	48
101-105	7	2	2	5	14	3	4	12	1		1	5	56
106-110	5	3	6	8	4	2	10	6	1	1		3	49
111-115	3	8	2	2	6	3	7	10	5	2		3	51
116-120	11	2	7	8	8	4	3	7	3	1	3	5	62
121-125	7	3	3	16	6	3	9	6	3	1	2	4	63
126-130	7	8	3	15	11	7	2	6	1	5	2	4	71
131-135	13	4	6	17	9	3	3	5	3	8	1	1	73
136-140	9	4	9	18	13	4	2	3	2	1	2	3	70
141-145	4	5	8	26	10	10	5	2	3	3	2	3	81
146-150	3	4	3	15	17	9	3	5	2		4	8	73
151-155	1	4	4	14	15	11	2	1	3	1	3	1	60
156-160	3	2	8	15	9	14	2	1	1	2			57
161-165	2	3	5	7	11	4	4	5	2	5	2	1	51
166-170	1	2	3	17	15	4	2	3		1	1	1	50
171-175	4	1	9	17	12	8	2	2	3	2	2	1	63
176-180	5	2	5	7	7	7	6	4	2			2	47
181-185	2	3	6	12	12	14	3	2		2	1	4	61
186-190	2	1	5	10	6	7	6		2	3	3		45
191-195	2		1	10	10	9	3	3	1	3	2		44
196-200	4	2	3	4	8	7	4	4	1			1	38
201-205		1	4	9	5	8	3	2	3			1	36

206-210	1	2	3	5	9	8	10	9	2		1		50
211-215		2	1	6	10	8	2	3	2	2		2	38
216-220	2	3	2	6	8	8	5	3	1				38
221-225	2	3		4	5	6	13	2	1	3	1	1	41
226-230	1		2	3	2	11	11	7	3	2	1	2	45
231-235	2	2	2	4	2	8	8	2	5	3	1	4	43
236-240		1	1	6	3	10	7		1	2		3	34
241-245	1		1	4	3	3	5	6	3	1		1	28
246-250		2	3	7	3	5	5	6	2	2	3	1	39
251-255	2	1	3	6	5	8	5	1	4	2	3		40
256-260		3	5	9	2	1	2	8	2		2		34
261-265	1	1	6	8	2	5	7	4	3	4	2	3	46
266-270	2		1	4	1	4	5	3	2	2	2	2	28
271-275	3	3	5	6	1	6	5	3	3	1		3	39
276-280	1		4	4	4	2	1	5	2	2		2	27
281-285	1	5	4	10	4	1	3	3	4	1		2	38
286-290	2		3	10	2	3	3		3	2	3	1	32
291-295	2	2	5	10	4	5	5	4	3	1	2	1	44
296-300	1	7	1	5	3	3		5	3	3		3	34
301-305	3	2	3	3	2	3		4	2	3	1	1	27
306-310	6	5	2	4	5	5	4	7	3	4	1	3	49
311-315		4	4	6	9	3	4		1	2	1		34
316-320		4	3	7	4	4	5	9	11	2	3	2	54
321-325	2	2	3	7	4	4	8	1	4		3	2	40
326-330	3	4	4	5	4	3	1	2	4	1	1	3	35
331-335	3	9	6	4	1	2	3	1	6	3	2	3	43
336-340	4	2	6	2	4	1	8	11	3			2	43
341-345	4		4	3	4	4	3	2	2	2	3	2	33
346-350	4	3	6	4	4	4	6	3		3	4	2	43
351-355	4	3	2	9	5	3	4	4	1	2	2	3	42
356-360	2	4	5	6	2	3	4	5	7		2	5	45
361-365	3	7	7	3	5	5	3	1	3	3	1	1	42
366-370	3	5	3	8	7	2	1	2	2	5	1	8	47
371-375	7	2	4	3	3	1	3	2	1	1	2	1	30
376-380	2	3	3	2	4		7	1	2	6		2	32
381-385	1	3	6	5	2	4	2	4	3	2		2	34
386-390	3	2	1	3	3	3	6	2	1		6	3	33
391-395	6	2	1	3	1	2	2		1	1		1	20
396-400	3	4	5	3	3	1	1	1	1	2	3	3	30
401-405	2	1	2	4	2		2	2	1	1		3	20
406-410	1	2	4	1	3	1	1		2	1	4	2	22
411-415	2	1	2			4						2	11
416-420	2		2	2	2			3		3	2	2	18

421-425	4	2	2	1	3	1			2	1		1	17
426-430	3		3	3	1					2	4	1	17
431-435	4				1	1	1	1	1				9
436-440			1	1	2		2		1	1	1	1	10
441-445				1					1	1			3
446-450	1	1		4	1	2	1					1	11
451-455	1						1	1			1	1	5
456-460		1					1		1	1	1		5
471-475								1			1		2
476-480							1						1
496-500			1			1	1						3
Grand Total	**291**	**248**	**420**	**670**	**450**	**391**	**355**	**259**	**168**	**134**	**105**	**176**	**3667**

Notes:
Sacramento Sucker year-classes Jan - May unclear; this species spawns opportunistically and, when conditions are good, can spawn more than once in a year. This life history strategy hinders identification of year-classes.

White catfish 1979-2012

Month Suisun

Sum of Count													
Std Length	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**Grand Total**
<1			3	8	11	138	29	266	63	37	49		604
6-10							2						2
11-15							19	11					30
16-20							50	18	4				72
21-25							81	44	12	1	1		139
26-30				2			50	52	31	3	1		139
31-35		1	1	1	1		23	84	63	10	9	1	194
36-40	2	5	4	15	4	1	12	88	83	34	12	1	261
41-45	3	7	11	19	12	3	1	73	97	56	32	2	316
46-50	3	9	22	28	13	3	2	37	77	37	34		265
51-55	4	6	23	29	31	10	2	21	38	19	25	3	211
56-60	2	3	10	20	30	7	3	4	13	13	6	1	112
61-65			7	6	24	20	7		4	3	3	1	75
66-70		1	2	2	15	12	12	6	2	1	1		54
71-75			3	12	16	22	15	7	4		1		80
76-80	1		1	8	6	23	13	12	2				66
81-85				5	3	17	24	14	3		1		67
86-90			3	12	3	10	20	20	5	1			74
91-95		1	3	14	6	8	21	25	4	4		1	87
96-100	1		1	6	6	5	11	17	6	1		3	57
101-105			4	4	11	6	13	15	7	2		1	63
106-110	1	3	4	9	21	7	16	21	8	7		1	98
111-115	3	2	3	7	17	8	8	23	10	4		2	87
116-120	1	2	6	11	15	11	4	11	11	1	2	1	76
121-125	1	2	5	14	20	10	12	17	5	2			88
126-130	1	1	4	7	16	16	6	11	3	2		1	68
131-135		1	1	5	12	14	9	6	8	2	1		59
136-140	1	1	5	6	11	14	12	5	2	1			58
141-145			1	3	14	8	9	2	3	1			41
146-150			2	3	11	18	8	5	2	2			51
151-155	1	1	2	8	10	11	9	4	3		1		50
156-160			5	6	5	12	15	8	6	1			58
161-165		1	5	4	5	19	10	10	2	2	1		59
166-170	1	1	4	2	6	18	11	8	3	2	1	1	58
171-175		2	2	9	8	8	9	5	3	6	3	2	57
176-180		2	7	15	2	15	13	8	4	6	3		75
181-185		2	6	15	4	9	13	3	5	2	2		61
186-190		3	5	10	10	13	11	10	7	6	2	2	79
191-195	4	2	6	17	8	14	10	8	6	7	5		87
196-200		3	8	16	9	12	11	5	2	7	4	3	80

201-205	2	1	5	14	8	8	10	14	8	5	4	1	80
206-210	2	3	14	11	11	12	13	8	4	9	6	1	94
211-215	2	8	11	19	5	8	7	8	10	9	4	2	93
216-220		4	14	17	6	9	14	8	6	5	4	2	89
221-225	1	4	6	10	8	6	10	9	7	9	4	2	76
226-230		5	11	9	6	6	11	6	6	10	5		75
231-235	1	4	8	10	5	4	6	7	7	14	3	2	71
236-240	1	4	9	9	6	3	6	6	6	11	12	4	77
241-245	3	7	12	6	4		5	6	6	13	7	4	73
246-250	1	2	4	6	7	4	6	5	6	6	1	2	50
251-255	2	3	2	4		1	6	2	3	10	8	2	43
256-260	3	4	8	4	3	3	6	2	3	9	5	5	55
261-265	2	1	6	6	3	1	4	1	4	6	6	1	41
266-270	2	3	3	8	1	2	3	3	4	7	3		39
271-275	3	4	3	3	2		3	3	1	4	4	1	31
276-280	1	3	6	4	2		3	1	1	6		2	29
281-285	1	6	6	3		1	1	3	2	10	6	2	41
286-290	1	4			3				3	5			16
291-295	2	1	3	2		3	1	1	1	2	3	4	23
296-300	2	1	3	1		1	2	1	1	5		2	19
301-305			2	1			1	1	2	2			9
306-310		1	1	2		1		1		1	1	1	9
311-315		3	2				1	1		1		1	9
316-320		3	1	1						1	1	1	8
321-325		1	2	1					1		1	3	9
326-330	2	1	1	1						1	1		7
331-335	1									1			2
336-340	1						1				1		3
341-345		2		1				1	1	1	1		7
346-350			1	1		1						1	4
356-360									1			1	2
361-365									1				1
371-375				1									1
376-380		1	1										2
391-395								1					1
396-400		1							1				2
406-410											1		1
416-420									1				1
431-435									1				1
456-460											1		1
496-500												1	1
Grand Total	**66**	**147**	**324**	**513**	**476**	**596**	**726**	**1083**	**709**	**446**	**293**	**75**	**5454**

Delta smelt Suisun

Month 1979-2012

Sum of Count Std Length	1	2	3	4	5	6	7	8	9	10	11	12	Grand Total
<1		1	17	228	836	83							1165
13-15					1								1
19-21					1								1
22-24					3	2							5
25-27					2			1					3
28-30				1	1	8	1	1					12
31-33					1	8	2	1					12
34-36						2	3				1		6
37-39						6	2			1			9
40-42						1	2	2	2		1		8
43-45		1					2	1		2	2	1	9
46-48	1	2					1			3	5	2	14
49-51	3	6				2		2	1	1	9	10	34
52-54	6	8						3	1	1	7	13	39
55-57	15	13	7	1				1		3	8	11	59
58-60	19	28	10	1	1				2	3	9	16	89
61-63	23	27	14	2				1			4	13	84
64-66	27	27	17	6	3					2	6	29	117
67-69	21	12	5	5			1				5	30	79
70-72	51	12	10	7		1				1	2	32	116
73-75	17	2	2	2	1				1		2	13	40
76-78	9	2	2	4								5	22
79-81	1					1		1	1			1	5
82-84												1	1
85-87		1											1
88-90									1			2	3
91-93					1								1
97-100												1	1
Grand Total	**193**	**142**	**84**	**257**	**851**	**114**	**14**	**14**	**9**	**17**	**61**	**180**	**1936**

Longfin Smelt Suisun

Month 1979-2012

Sum of Count **Std Length**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**Grand Total**
<1		382	925	1514	1444	46		437	432	46	256	338	5820
10-12				1	4	1							6
13-15				1	9								10
16-18			1	4					1				6
19-21			12	16	10	1		1					40
22-24		1	14	71	37	5	2						130
25-27		4	27	122	94	15	8	5		1			276
28-30		1	48	119	110	25	7	14	4	1	1		330
31-33		1	6	74	45	24	25	13	4		1		193
34-36			1	28	24	8	9	18	1	5	1		95
37-39				16	12	9	6	22	3	14	7		89
40-42				5	5	4	6	25	10	17	17		89
43-45				1	3	5	2	40	22	39	76	4	192
46-48	2	1		1			2	38	32	79	210	18	383
49-51	17	3			2	1	3	40	63	70	340	74	613
52-54	33	2		1	2		5	16	43	65	200	109	476
55-57	62	7	4		1		6	24	54	46	166	128	498
58-60	78	12	3	1			5	16	59	54	123	150	501
61-63	97	21	5	2			1	15	44	48	122	155	510
64-66	100	30	7	1				7	40	23	120	166	494
67-69	94	31	10	3				1	35	28	88	174	464
70-72	129	33	12	11					13	11	114	222	545
73-75	103	38	19	17	3				5	9	60	177	431
76-78	77	19	16	13	3	1			3	6	45	118	301
79-81	55	11	11	7	1	1			2	4	26	118	236
82-84	9	9	6	6	2		1			6	19	64	122
85-87	10	3	1	9	1	1			3	4	11	32	75
88-90	2	1	2	1	2	1			2	3	8	13	35
91-93	4	1		1	1					5	7	6	25
94-96	1	3	1	1	1					4	6	4	21
97-99					2				1	2	6	7	18
100-102	2	3								2	2	5	14
103-105											2	2	4
106-108		1											1
109-111	1										1	4	6
112-114		1		1								1	3
154-156											1		1
Grand Total	**876**	**619**	**1131**	**2048**	**1818**	**148**	**88**	**732**	**876**	**592**	**2036**	**2089**	**13053**

Prickly sculpin 1979-2012

Month Suisun

Sum of Count Std Length	1	2	3	4	5	6	7	8	9	10	11	12	Grand Total
<1	1		309	268	384	174	39						1175
5-6			2										2
7-8			3										3
9-10			1	2									3
11-12			17	13									30
13-14		1	16	19	4	1							41
15-16		1	31	49	9	1							91
17-18		3	52	83	11	6							155
19-20		8	50	167	37	6							268
21-22		5	70	181	62	10	4						332
23-24		3	78	206	76	15	5	1					384
25-26	1	4	56	279	111	25	3	3	1				483
27-28		2	35	257	133	27	5	2					461
29-30	2	1	37	268	200	64	17	10	2				601
31-32			14	209	218	69	33	6	2	1			552
33-34		3	7	149	196	84	18	7	3			1	468
35-36	2	1	6	131	223	82	20	14	1	2			482
37-38			2	87	227	79	37	7	2	1	1		443
39-40	1	5	3	67	252	111	35	11	4	5	1	1	496
41-42		1	4	29	166	96	50	13	5	7	1	2	374
43-44	2	3	2	20	180	96	38	11	4		1	2	359
45-46	8	8	2	10	155	117	50	20	8	10	7	1	396
47-48	6	7	1	13	94	105	45	15	8	9	1	3	307
49-50	4	5	1	5	95	120	54	16	4	10	6	5	325
51-52	4	3	3	5	77	97	51	21	10	1	2	2	276
53-54	5	3	5	5	38	79	134	19	5	9	3	8	313
55-56	8	10	3	7	26	87	56	22	11	19	3	4	256
57-58	9	10	2	6	18	49	33	33	8	9	7	5	189
59-60	9	10	5	8	6	58	46	15	10	1	4	7	179
61-62	7	19	5	12	11	38	33	22	9	15	11	7	189
63-64	7	9	4	11	12	32	24	13	6	8	7	6	139
65-66	9	15	9	24	9	15	21	16	5	7	7	11	148
67-68	7	15	16	14	5	14	10	10	5	12	4	8	120
69-70	12	8	8	10	8	7	25	20	9	7	8	6	128
71-72	5	10	2	14	11	3	18	10	5	10	5	7	100
73-74	10	9	7	13	10	4	11	6	5	4	2	3	84
75-76	5	8	10	16	14	4	6	14	7	6	10	5	105
77-78	4	3	7	10	16	2	5	7	5	5	6	1	71
79-80	4	6	5	18	14	6	5	8	5	3	6	5	85
81-82	5	7	1	7	20	3	6	8	5	4	8	5	79

83-84	6	2	4	4	12	4	4	5	2	6	5	5	59
85-86	2	6	5	10	17	6	6	3	4	5	2	4	70
87-88	3		2	8	8	9	3	4	1	3	3	3	47
89-90	5	2	2	9	12	7	8	5	2	1		1	54
91-92	1	4	2	6	13	6	4	5	2	2	2	2	49
93-94			3	7	20	6	2	3	1	4	2	3	51
95-96	2	3	2	4	6	5	6	1	3	1	3		36
97-98	2		2	2	6	5	4	2	5	2		1	31
99-100		1		5	8	3	6	2	1	1			27
101-102			1	4	8	6	4	1	1	2			27
103-104	1	1	2	6	12	4	9	4	3	2		2	46
105-106	2		1	4	9	6	9	3		1		2	37
107-108	1			1	1	3		2	1	1			10
109-110	2		1	2	3	3	3	5	1	1		3	24
111-112	1			2	1	4	3		1	1	2		15
113-114				1		4	2	3	1	1	1	1	14
115-116		1	1	1	2	2	2	2	2				13
117-118		1		1	1	1		2	2	2			10
119-120			1	2				1	3				7
121-122		1		1	1		1		1		1		6
123-124		1		2						1			4
125-126				2	1	1	1		1			1	7
127-128			1		2				2	1	1		7
129-130			1	1		1							3
131-132					1	1							2
133-134		1		1		1	1						4
135-136				1		1						2	4
137-138						1			1				2
141-142					1								1
151-152												1	1
155-156							1						1
161-162	1												1
227-228												1	1
Grand Total	**166**	**230**	**922**	**2779**	**3273**	**1876**	**1016**	**433**	**195**	**203**	**133**	**137**	**11363**

Striped bass 1979-2012

Month Suisun

Sum of Count Std length	1	2	3	4	5	6	7	8	9	10	11	12	Grand Total
<1	3	21	1	248	7515	23284	10047	5714	2519	1158	186	19	50715
6-10					14	24	15			1			54
11-15				1	257	342	174	2					776
16-20		5	1	1	514	1258	423	26	1				2229
21-25		17	4	5	453	1781	979	101	7				3347
26-30	2	5	4	4	152	1410	1568	272	14		1		3432
31-35			3	2	8	910	1690	492	33	3	1		3142
36-40	2		1		4	564	1585	791	91	4	4	1	3047
41-45	1	4				235	1337	936	296	20	8	4	2841
46-50	4	4				121	1075	1086	583	79	16	10	2978
51-55	25	33	8	2	2	83	755	1095	915	180	59	32	3189
56-60	73	52	30	11	2	48	536	1174	1039	267	132	67	3431
61-65	121	101	47	19	2	17	350	964	1055	350	211	93	3330
66-70	160	94	66	27	3	4	204	788	934	404	277	154	3115
71-75	163	126	81	54	8	2	122	568	799	432	325	160	2840
76-80	181	107	89	94	14	5	42	426	586	392	313	176	2425
81-85	173	115	115	121	29	3	23	279	471	320	259	194	2102
86-90	141	99	82	142	43	3	17	186	317	243	205	150	1628
91-95	118	91	93	133	63	8	7	95	205	219	133	120	1285
96-100	85	76	66	140	91	14	5	64	156	166	119	88	1070
101-105	78	60	72	161	81	20	2	35	114	112	80	63	878
106-110	62	59	68	140	113	37	6	9	80	83	51	48	756
111-115	27	30	57	164	125	44	11	11	51	83	45	36	684
116-120	43	41	39	96	121	58	9	7	42	46	23	33	558
121-125	22	24	43	84	117	68	9	4	17	28	22	25	463
126-130	15	19	30	81	135	61	29	6	9	13	26	16	440
131-135	22	15	21	52	79	94	32	10	8	13	12	8	366
136-140	13	8	23	49	77	65	35	11	3	5	6	10	305
141-145	5	9	13	41	71	82	36	23	5	7	11	8	311
146-150	5	3	19	22	41	69	68	22	6	3	7	9	274
151-155	8	6	5	24	37	43	57	27	11	6	4	4	232
156-160	6	6	2	18	28	51	68	46	18	3	6	10	262
161-165	7	8	5	13	25	43	60	45	13	11	1	5	236
166-170	7	5	6	11	28	24	49	43	19	11	3	9	215
171-175	7	8	13	8	12	23	49	39	28	12	9	10	218
176-180	7	3	6	8	14	19	40	57	35	7	11	9	216
181-185	3	5	3	10	11	7	39	41	34	14	12	8	187
186-190	8	9	9	8	10	12	37	37	26	10	12	6	184
191-195	10	7	5	9	8	10	28	29	27	12	15	14	174
196-200	10	7	14	9	10	8	18	30	28	10	13	12	169
201-205	10	4	9	9	7	10	15	22	28	12	14	7	147
206-210	7	5	9	13	12	6	10	14	22	11	13	9	131
211-215	9	5	7	8	9	9	7	17	21	17	10	10	129
216-220	9	4	16	13	4	8	7	9	18	12	14	5	119
221-225	5	11	7	12	10	5	3	12	10	21	5	7	108
226-230	8	11	5	5	5	4	8	5	15	11	7	4	88

231-235	3	5	4	10	8	9	3	6	7	9	6	2	72
236-240	10	4	9	8	13	1	1	5	6	8	6	4	75
241-245	3	2	6	3	11	6	3	2	6	7	5	3	57
246-250	1	4	3	2	10	6	6	9	2	6	5		54
251-255	2	3	3	6	7	6	4	1	3		5	4	44
256-260	3	3	2	6	7	7	4	6	4	5	1	1	49
261-265	2		1	6	7	4	7	3	3	4	2	1	40
266-270	2	3	2	5	4	2	4	5	6	3	2	2	40
271-275	1	3	2	3		4	2	4	2	1	2	1	25
276-280	1		3	3	2	5	1	4	4	1	3		27
281-285	2	1	4	2	2	3	4	5	3	3		1	30
286-290	3		1		4		6		2		4		20
291-295	3	1			1	3	2	2		1	2	1	16
296-300	2	1	2	1	1		3	5		4	1	2	22
301-305		3	1	1		2	3	1	2	1	1		15
306-310	1	2	1			2	3	3	1	2	3	4	22
311-315	1				1	2		1	1	1		3	10
316-320	2	2		1	1	4	2	1	1		2	2	18
321-325	1	1	1		3		1	1		1	1		10
326-330	3	1							3			2	9
331-335		1		3		1			2	1		2	10
336-340				1	2	1	1		2	1	2	1	11
341-345	1	2	2		1			1	2	2		2	13
346-350				1	1		2		1	3	1	2	11
351-355	1	1		1				1	1		1	1	7
356-360	2		3		2				1	2		2	12
361-365	1	2	2		2	2	1		1	4	1		16
366-370	3	1	2	1		1					1	1	10
371-375		1	1						1	1	1	2	7
376-380	1	1	2			2		1		1	1		9
381-385	1	1	1	1		2		1					7
386-390	1	1	1	1					1			2	7
391-395	3	1			2	1	2					1	10
396-400	2	2	1		2			3		3	1	1	15
401-405	1	2	2										5
406-410	1	1		1			2						5
411-415						2			1	1	1		5
416-420	3	1	1	1	2				1			1	10
421-425	2	1	1							1	1	1	7
426-430			2		2				1		1	1	7
431-435												2	2
436-440				1				1	1				3
441-445		1							2			1	4
446-450	3	1				1					1	1	7
451-455	1	1											2
456-460	1			1							2	2	6
466-470						1	2				1		4
471-475			1									1	2
476-480	1	1		1						1			4
481-485			1							1			2

486-490					1							1	2
491-495				1									1
496-500					1								1
501-505						1				1			2
506-510		1										1	2
516-520		1		1			1						3
521-525						1							1
526-530		2	2		1			1					6
536-540	1												1
541-545									1				1
546-550	2	1			1			1	1		1		7
551-555											1	1	2
556-560		1						1				1	3
561-565							1						1
566-570	1	1											2
571-575				1									1
576-580	1											1	2
581-585	1												1
596-600												1	1
606-610						1							1
616-620									1				1
621-625						1							1
626-630										1	1		2
646-650												1	1
711-715												1	1
736-740												1	1
751-755				1									1
786-790		1											1
896-900												1	1
916-920										1			1
936-940												1	1
946-950	1												1
Grand Total	**1747**	**1392**	**1267**	**2147**	**10466**	**31080**	**21757**	**15745**	**10786**	**4893**	**2751**	**1724**	**105755**

Black crappie 1979-2012

Month Suisun

Sum of Count Std Length	1	2	3	4	5	6	7	8	9	10	11	12	Grand Total
<1							95	185	63	1			344
11-15						1							1
16-20					5	3							8
21-25					4	5	2						11
26-30					1	13	10	2				1	27
31-35					1	14	38	8					61
36-40					1	13	57	33	5	2		1	112
41-45	1				1	8	51	64	32	12	1	5	175
46-50	4		3		1	10	61	82	68	30	3	10	272
51-55		1	4	1	2	1	57	40	44	44	6	15	215
56-60	2		6	5		1	20	13	16	13	2	9	87
61-65	2		6	2		2	7	1	6	13	5	7	51
66-70	3	1	2	1	3	2	2	2	13	12	5	7	53
71-75	3		2	1	3	3	4	3	6	7	1		33
76-80	1			1	3	1	3		4	4	9	2	28
81-85	1	1	1	4	1	5	3	1	3	3	5	1	29
86-90	1	1	1		4	5		1	2	1	3		19
91-95					1	6	4	2		2		1	16
96-100		1	4		2	4	5	2	1	1	1	2	23
101-105	1			1			6	6	1	1		1	17
106-110		1		2	3	4	3	1	3		1	1	19
111-115	1			1		1	5		4	3	4		19
116-120	1					2	4	3	1	1	2		14
121-125	1		3				7			2	2		15
126-130	4		1			2	2		1		6	2	18
131-135	2	1		1	3		2			2	3	3	17
136-140	1	1	3			2		2	2		7	3	21
141-145	2	1	1	2		1	1	1		3	5	1	18
146-150	4	2	2		1		1	2	2	2	3	2	21
151-155	4	1	2	1	1			4	1	3	4	2	23
156-160	2		1	1	1		1		4		3	2	15
161-165	1		2	1	1	1					5	2	13
166-170	1							2	1	2	2	2	10
171-175		1	2				1	2		1	3	1	11
176-180	2	2	1	2						1		1	9
181-185	1	1	2							2	3	3	12
186-190	3	3	1			1				2	3	1	14
191-195	3	1	3					1		1		3	12
196-200									1		1	1	3
201-205			1		1					3	1	1	7

206-210			1	1				1			1	2	6
211-215	1					1				1	2		5
216-220	1		1	1									3
221-225			1	1							1		3
226-230	1										2		3
231-235	1		1							2			4
236-240	3									1			4
241-245	1	1											2
246-250											1		1
256-260	1				1							1	3
261-265	1		1	1									3
286-290												1	1
316-320											1		1
866-870					1								1
Grand Total	**62**	**21**	**59**	**31**	**46**	**112**	**452**	**464**	**284**	**178**	**107**	**97**	**1913**

Tule perch 1979-2012

Month Suisun

Sum of Count													
Std Length	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**Grand Total**
<1	357	28	3	10	255	207	471	79	33	19		91	1553
9-10	1												1
13-14	1				1				1				3
17-18					2								2
19-20					2								2
21-22				4	4			1					9
23-24				8	9	2							19
25-26				10	32						1		43
27-28		1		35	75	2	2						115
29-30				17	159	9							185
31-32				8	116	13	1						138
33-34				1	82	7							90
35-36				1	75	20	2						98
37-38				1	61	34	6	1					103
39-40					53	46	14						113
41-42	1				18	71	20	2	2				114
43-44	1				8	87	8	2			1		107
45-46	1				9	104	27	2					143
47-48	1				3	76	40	5	1				126
49-50						90	73	9				1	173
51-52	1	2				87	63	14	1	2			170
53-54						62	84	43	7	3		1	200
55-56	3	1				57	110	67	7	3	1	1	250
57-58	3	3	1		2	48	119	92	8	1		1	278
59-60	12	2				30	126	138	31	9	2	5	355
61-62	18	5	1		1	26	98	139	36	9	8	5	346
63-64	32	12			2	11	102	134	42	17	10	8	370
65-66	37	20	5	3		10	88	134	48	24	16	25	410
67-68	49	41	3		1	8	74	127	65	28	14	24	434
69-70	80	47	7	4	1	6	81	146	88	52	23	47	582
71-72	85	40	9	6			54	113	99	42	33	49	530
73-74	90	62	19	11		3	27	95	111	67	45	80	610
75-76	131	54	22	15	5	1	30	99	116	83	57	82	695
77-78	132	50	23	18	5	1	18	78	111	86	47	69	638
79-80	158	59	28	25	7	1	14	88	90	86	71	112	739
81-82	144	56	31	49	11	3	11	46	78	87	57	110	683
83-84	148	47	36	48	13	1	10	35	60	60	57	91	606
85-86	145	71	52	40	7	8	5	55	47	60	47	96	633
87-88	101	61	48	48	17	5	10	30	38	40	40	67	505
89-90	111	59	48	60	14	8	12	32	39	37	37	76	533

91-92	101	50	51	52	32	8	9	22	23	35	30	54	467
93-94	78	47	59	39	26	9	12	16	29	30	29	56	430
95-96	67	51	42	53	32	16	15	17	21	24	28	48	414
97-98	52	32	46	36	24	24	20	12	13	17	22	37	335
99-100	23	19	36	52	31	28	22	19	18	19	10	20	297
101-102	31	25	21	35	22	19	18	22	14	16	18	19	260
103-104	37	19	38	35	34	25	35	42	8	8	19	19	319
105-106	39	19	22	44	39	38	30	23	16	25	18	21	334
107-108	40	15	34	22	28	36	31	31	17	15	7	15	291
109-110	27	23	40	33	38	56	43	49	30	37	21	22	419
111-112	37	22	16	36	17	37	35	40	30	22	26	24	342
113-114	31	24	23	32	20	34	45	29	26	22	13	17	316
115-116	36	15	18	21	33	33	43	37	22	24	13	30	325
117-118	43	22	20	27	28	18	34	31	23	15	15	29	305
119-120	43	27	19	36	25	36	30	49	22	29	11	33	360
121-122	29	27	21	27	25	10	24	34	31	29	22	26	305
123-124	34	14	13	22	18	17	29	22	26	25	18	25	263
125-126	28	31	18	26	16	19	29	34	20	26	15	28	290
127-128	18	20	13	25	11	16	22	30	18	10	13	21	217
129-130	30	26	13	23	21	15	26	32	19	20	8	22	255
131-132	20	13	15	22	15	13	27	15	21	14	19	29	223
133-134	22	9	6	10	13	13	19	16	10	7	7	13	145
135-136	15	16	13	18	15	13	13	18	13	12	8	18	172
137-138	15	9	11	12	14	16	16	12	6	7	5	18	141
139-140	9	9	16	28	5	18	14	16	8	6	3	11	143
141-142	10	9	11	24	8	6	9	12	6	4	7	7	113
143-144	8	8	4	9	2	11	9	9	6	3	2	8	79
145-146	9	7	9	10	7	7	9	6	5	9	3	7	88
147-148	5	5	6	6	4	7	7	2	5	3	1	6	57
149-150	5	6	4	9	8	6	12	8	3	3	3	7	74
151-152	1	5	2	4	5	4	3	2	1	3	1	3	34
153-154	2	1	2	4	3	2	2	7	2	2	2	2	31
155-156	3	2	1	5	3	2	3	3	3	1		4	30
157-158	5	2	1	2	2	3	2		3		2	2	24
159-160		3	3	6	2	2	3	4	1	2		2	28
161-162	1	1		1				1	1			1	6
163-164				1	1		1		2				5
165-166		1		2	2		4				1		10
167-168				1	1		1	2				1	6
169-170				1	1						1		3
171-172									1			1	2
173-174				2									2
175-176		1				1						2	4
179-180							1		1				2

183-184											1		1
185-186			1				1		1				3
189-190										1			1
191-192				1									1
195-196								1					1
199-200										1			1
239-240			1				1						2
269-270						1							1
411-412	1												1
Grand Total	**2798**	**1356**	**1005**	**1276**	**1681**	**1763**	**2509**	**2531**	**1684**	**1341**	**989**	**1749**	**20682**

Shimofuri goby 1979-2012

Month Suisun

Sum of Count													
Std Length	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**Grand Total**
0		62	9	77		904	2371	762	184	45			4414
7						1							1
8						3	1	1					5
9						1	1	1	1				4
10					1	1	8	15	3				28
11						3	25	23	2				53
12					1	6	67	84	3				161
13						9	59	106	2				176
14			1			12	106	126	10	1			256
15			2		5	20	129	162	14	2			334
16			1		10	26	97	131	27	2			294
17					4	34	85	96	35				254
18					9	42	100	92	18	1	1		263
19			1		2	21	62	63	24	3		1	177
20			1		5	17	76	92	25	3	1		220
21				1		15	35	45	21	4			121
22			2			14	49	54	18	4			141
23	1					6	26	36	39	6	2		116
24	1	1		2		2	24	49	31	9	3	1	123
25	1		3			7	28	45	32	5	1	1	123
26	1		2			4	26	36	34	7	1		111
27	2	1	1		1	1	30	42	28	9	6	1	122
28	1		2	3	1	5	26	25	40	8	7	1	119
29	1	1	2				29	32	29	13	4	2	113
30	3		2	1	2	2	30	50	45	7	7	2	151
31	6	3	2	1	1	1	24	30	35	10	5		118
32	7	3		1		1	17	34	42	22	10	3	140
33		5	6		1		12	21	37	17	10	3	112
34	4	5	7		1		18	33	36	20	10	3	137
35	5	10	12	4	4		17	53	30	10	11	8	164
36	3	7	3		2	1	17	26	41	16	10	5	131
37	6	4	8	7	2		9	31	22	20	14	3	126
38	7	7	10	4	3		19	37	33	23	18	5	166
39	2	10	13	5	3	1	12	31	25	12	5	5	124
40	6	17	12	9	7	3	11	38	29	19	19	3	173
41	4	11	6	13	3	3	6	21	22	8	11	2	110
42	8	14	14	22	10	3	14	25	34	14	15	3	176
43	6	9	10	16	6	2	4	17	20	15	7	7	119
44	7	12	14	22	11	3	4	14	17	15	10	6	135
45	7	14	24	28	17	8	9	29	19	19	10	6	190

46	5	7	17	24	6	7	1	15	10	14	8	4	118
47	3	14	11	24	12	1	3	17	15	17	9	6	132
48	8	10	18	27	13	7	4	11	22	15	9	3	147
49	5	9	11	29	13	6	5	8	13	14	7	6	126
50	4	7	16	24	26	8	5	11	17	15	4	5	142
51	3	10	8	19	19	6		10	13	9	9	3	109
52	1	13	17	16	9	7	3	6	7	4	4	4	91
53	1	12	12	15	11	6	4	10	10	9	12	3	105
54	5	10	15	22	8	10	1	8	13	8	6	2	108
55	6	11	20	29	9	10	1	6	16	14	4	5	131
56	4	8	17	11	5	7	2	7	9	13	7	3	93
57	3	2	4	14	6	5	1	3	10	6	4	6	64
58	1	6	19	17	2	2	2	4	7	9	5	2	76
59	1	2	9	10	3			2	2	7	2	1	39
60	4	4	18	20	6	2	2	6	4	12	9	2	89
61	2	3	6	13	3	6		4	5	9	3	4	58
62	3	3	8	8	5	3			9	6	3	1	49
63	2	4	7	6	1	1			2	4	6	1	34
64	3	4	6	9	6		1	1	6	3	2	2	43
65	1	7	12	11	5	1			3	3	6	5	54
66		3	5	3	2				4	2	2	1	22
67	2	5	3	2			1		1	5	2	1	22
68	1	3	6	4	1	1	1		3	3	3		26
69	2		3	2	2	1			1		3		14
70	1	2	3	11					1	5	4	1	28
71	1	2		3	1			1	2	3			13
72	1	2	5	2					1			1	12
73	1	4		3				1		1			10
74		2	4	1						3			10
75				2	1	1				1		3	8
76		1	2	2	1	1			1				8
77					1								1
78			5	1							1		7
79			2	1									3
80									1	1	1		3
81			2		1		1						4
82		1	2	1							1	2	7
83				2									2
86			1	2									3
90				1									1
95	1								1				2
111				1									1
115				1									1
150				1									1
Grand Total	**164**	**367**	**464**	**610**	**290**	**1281**	**3721**	**2739**	**1316**	**584**	**334**	**148**	**12018**

Shokihaze goby 1979-2012

Month Suisun

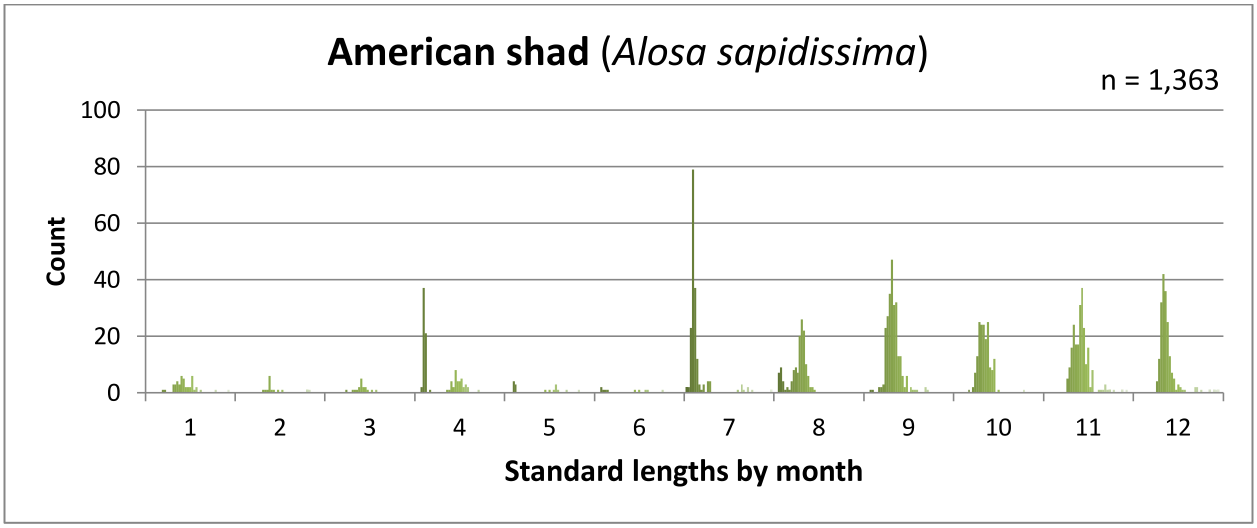
Sum of Count Std Length	1	2	3	4	5	6	7	8	9	10	11	12	Grand Total
<1				0	1		80	18	2				101
9-10							1						1
11-12							1	2					3
13-14							7	9		1			17
15-16					1		5	16	1	1			24
17-18							8	17	4	1			30
19-20							10	6	12	2	1	1	32
21-22			1				6	6	14	4			31
23-24			1				4	15	10	5			35
25-26	1						4	14	18	8			45
27-28		2					1	23	11	11	2		50
29-30		1		2				19	10	2	1	1	36
31-32			1					22	6	5	1		35
33-34		1		2				10	13	12	1		39
35-36				2				5	9	9			25
37-38	1				1			2	6	7		1	18
39-40				2	3			3	10	7	1		26
41-42					1			1	2	4	2		10
43-44		1						1	8	4	1	1	16
45-46			2		3			1	4	3	1		14
47-48		1			4	2		1		4	1	1	14
49-50	1						1	1	2	4			9
51-52			1	1		1		1	2	1	1	1	9
53-54		1	1		1	1	1	1	1	2	2		11
55-56	1			2			2	1	2	3		1	12
57-58				1	3	1				2	2		9
59-60				1	1	2		1					5
61-62	1				3	3	1						8
63-64			1		2	1		1		1			6
65-66			1				1	1	3				6
67-68						1							1
69-70		1		3		2	1		2				9
71-72							2			3			5
73-74					1	1		2					4
75-76					2	1	1	1					5
77-78												1	1
79-80						1	1	1					3
81-82									2				2
83-84						1			1			1	3
85-86						2							2
89-90					1				1				2
93-94										1	1		2
139-141									1				1
Grand Total	**5**	**8**	**9**	**16**	**28**	**20**	**138**	**202**	**157**	**107**	**18**	**9**	**717**

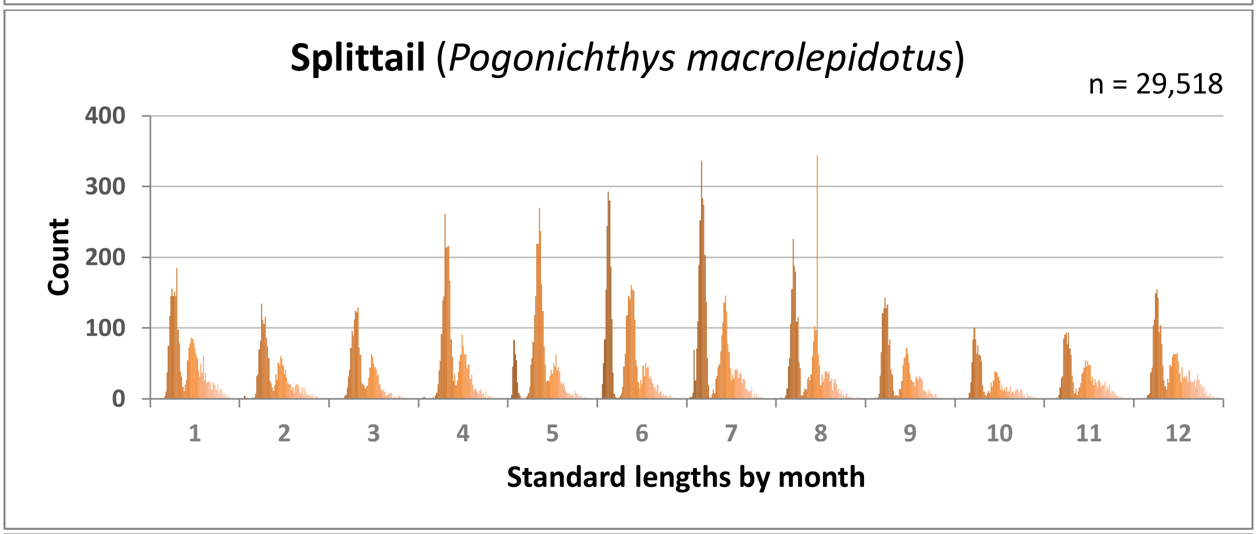
Starry flounder 1979-2012

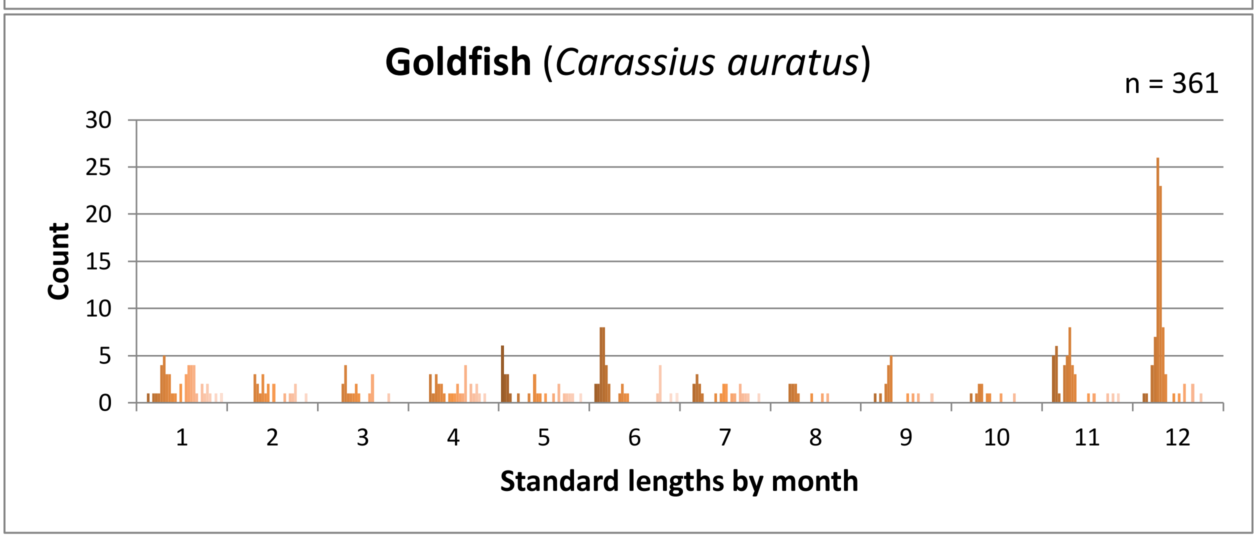
Month Suisun

Sum of Count													
Std Length	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**Grand Total**
<1					7	116			2				125
1-10				2									2
11-20				11	25	8							44
21-30		1		10	54	79	15	5					164
31-40		1	1	2	52	103	124	35	4			1	323
41-50		1			20	60	89	52	15				237
51-60	2	2	2		2	27	54	35	31		4	4	163
61-70	5	9	2			11	39	23	38	12	16	7	162
71-80	18	14	13	7	4	3	8	19	39	13	15	21	174
81-90	14	29	31	19	5	1		12	18	17	19	17	182
91-100	16	19	41	26	3		2	7	4	14	17	13	162
101-110	16	9	39	22	2			2	1	10	4	17	122
111-120	7	12	34	17	6				1	8	9	3	97
121-130	4	18	15	12	6				1	3	8	4	71
131-140	3	15	11	6	3		1			2	1		42
141-150	3	2	12	8	4	2			2	1	1		35
151-160		1	9	6		2			1	2	1	1	23
161-170		5	4	2	1		1		1	1			15
171-180	1	4	1	1	1		1		2				11
181-190			3	2				1		1	1	2	10
191-200				1		1			4	2			8
201-210	1							1	1	3	3	3	12
211-220	2	1						1	1	2	2	4	13
221-230	4	4							1	1	7	7	24
231-240	1	2							1	1	3	1	9
241-250	1							1			1	3	6
251-260		1								1	2	2	6
261-270	1											1	2
291-300			1										1
311-320												1	1
321-330		1											1
441-450						1							1
Grand Total	**99**	**151**	**219**	**154**	**195**	**414**	**334**	**194**	**168**	**94**	**114**	**112**	**2248**

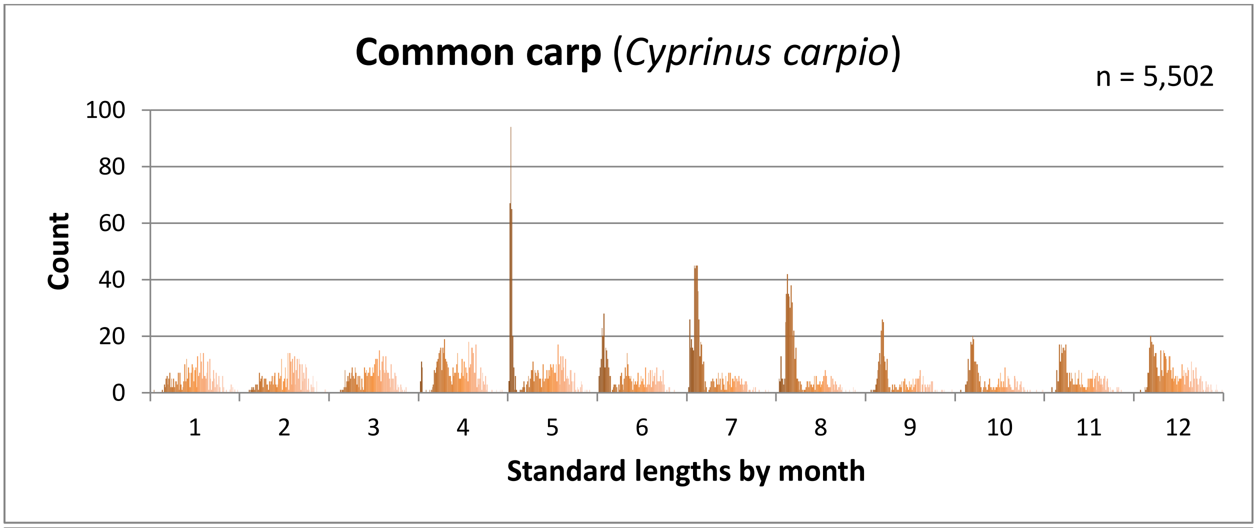
Appendix 3
Year-class histograms

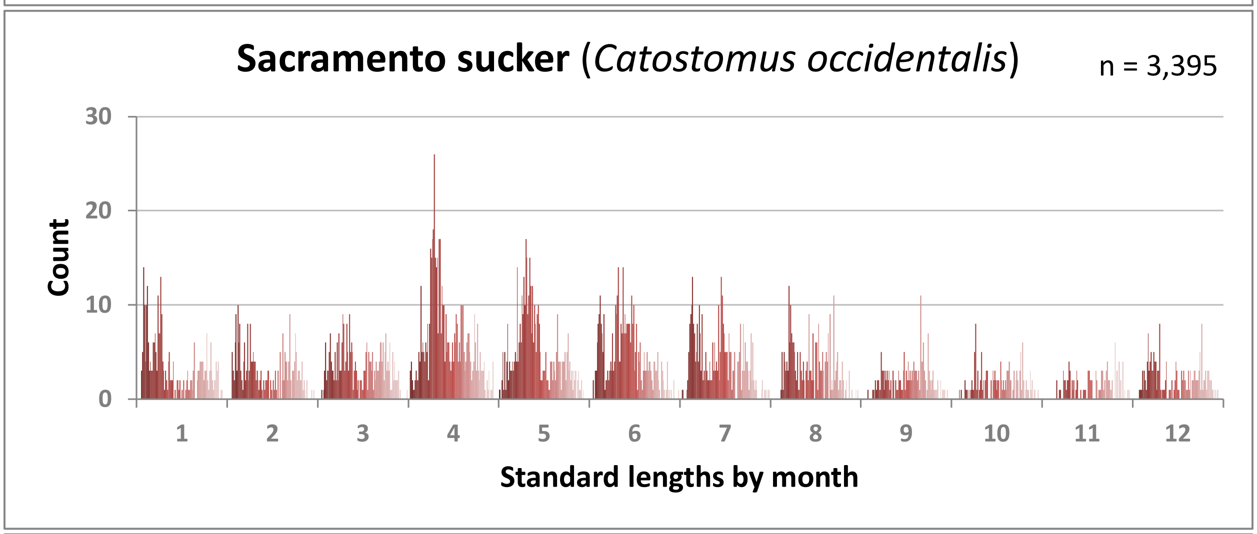


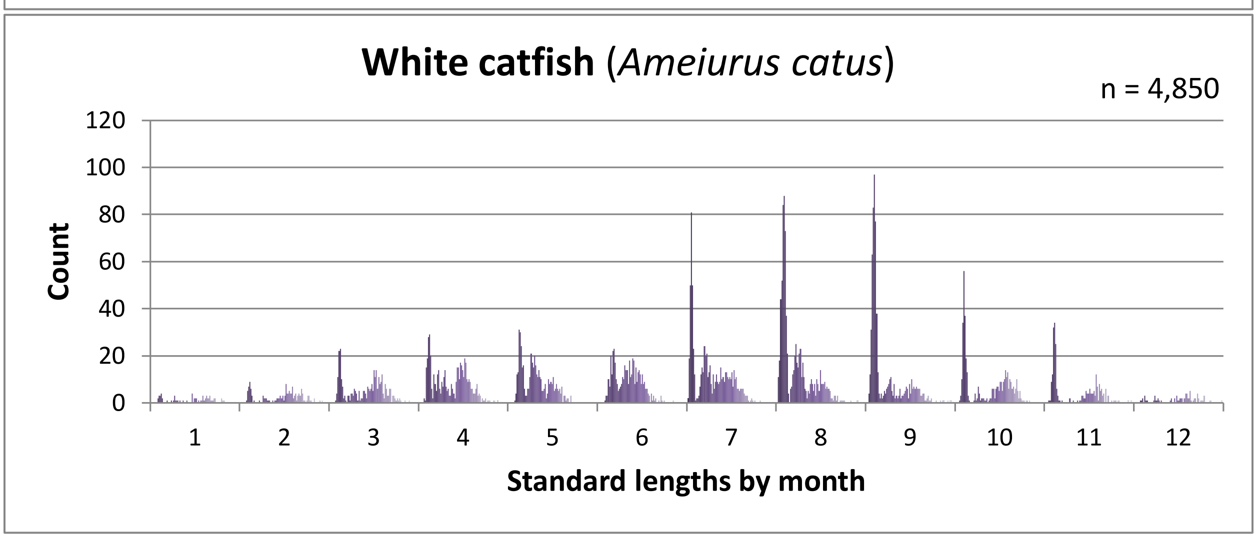




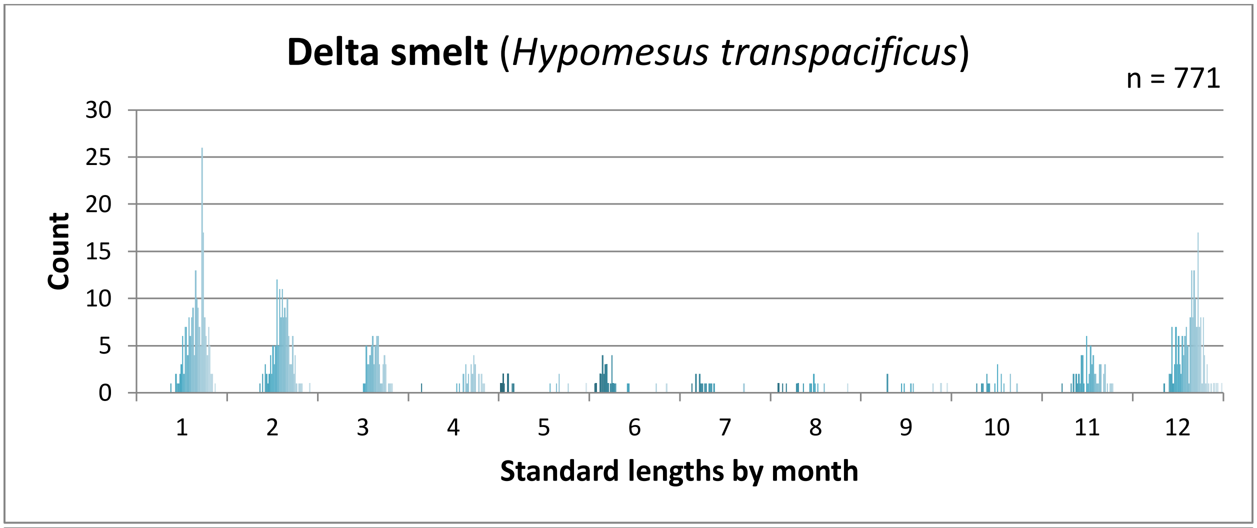
Year-class histograms (continued)

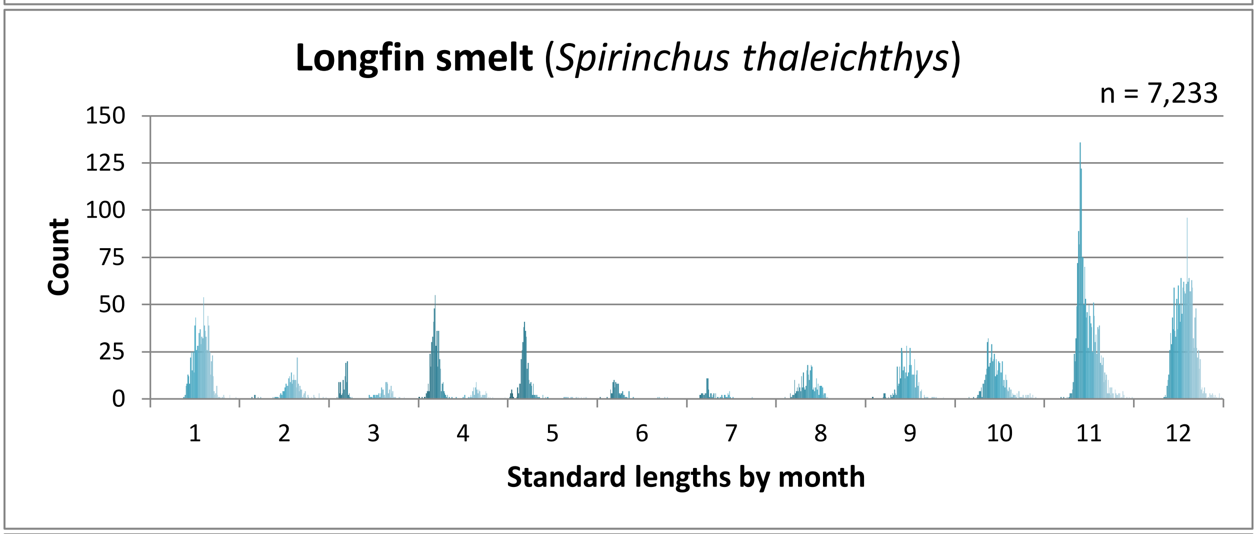


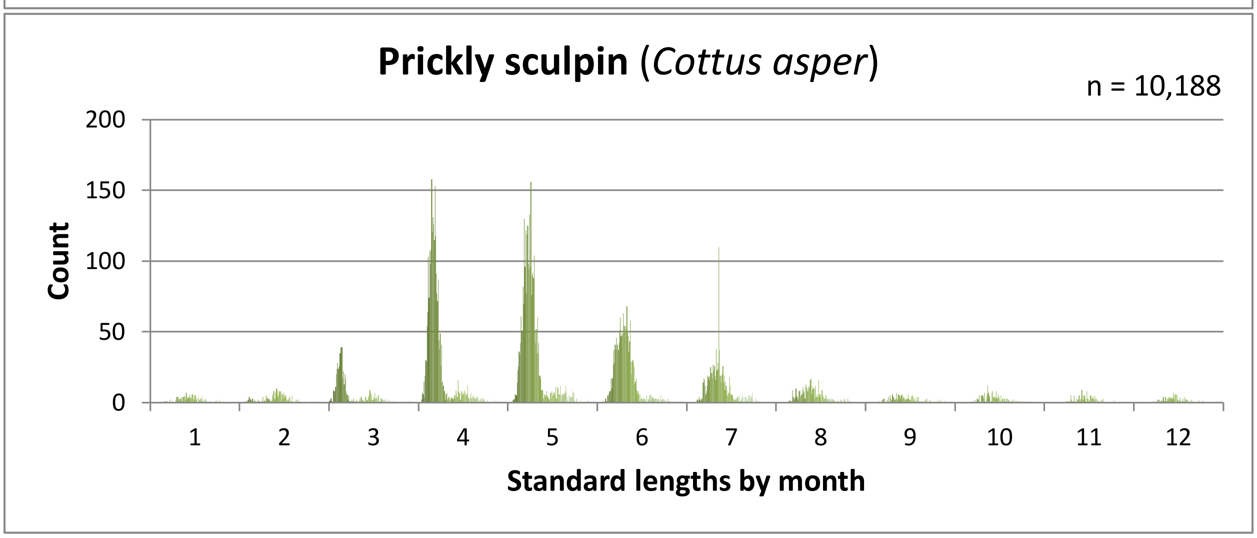




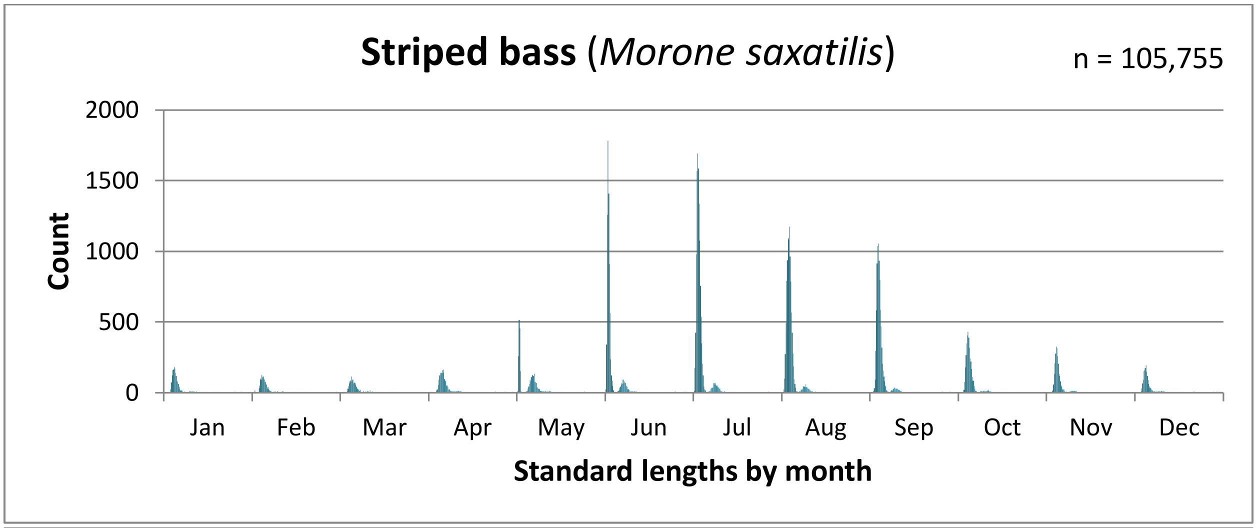
Year-class histograms (continued)

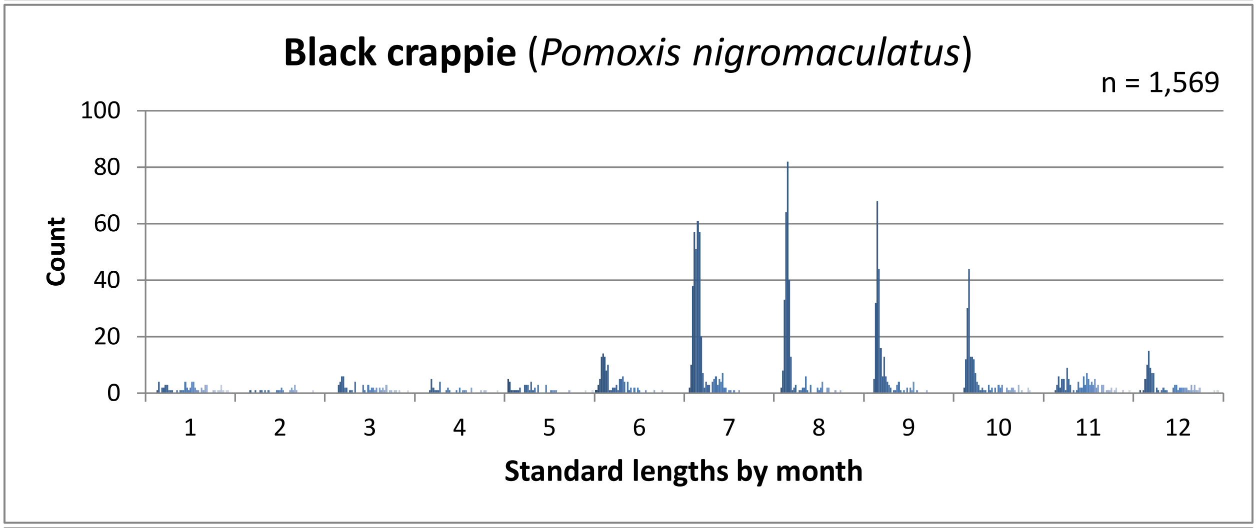


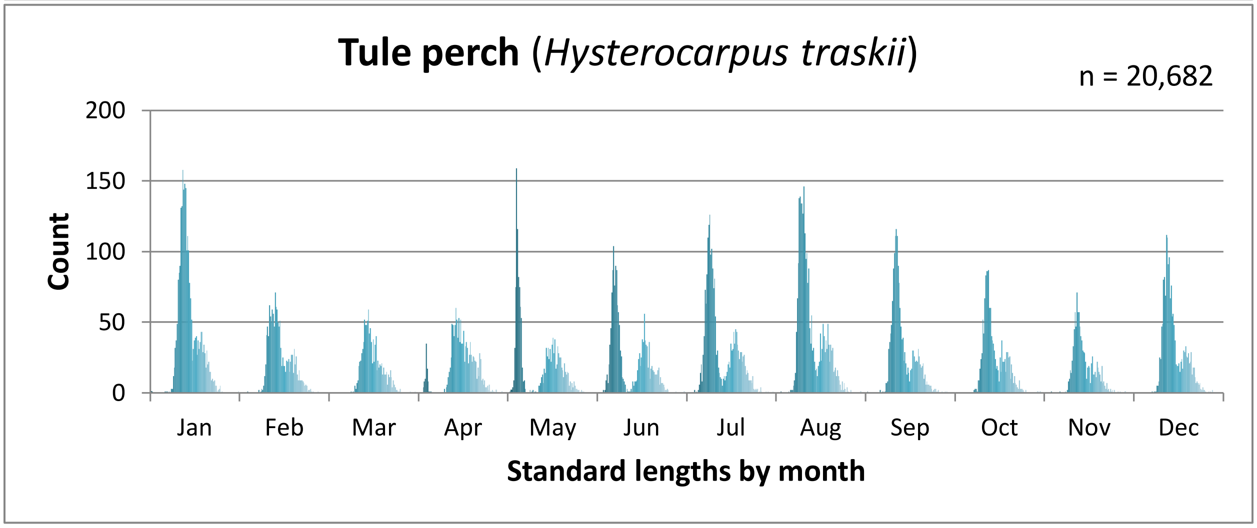




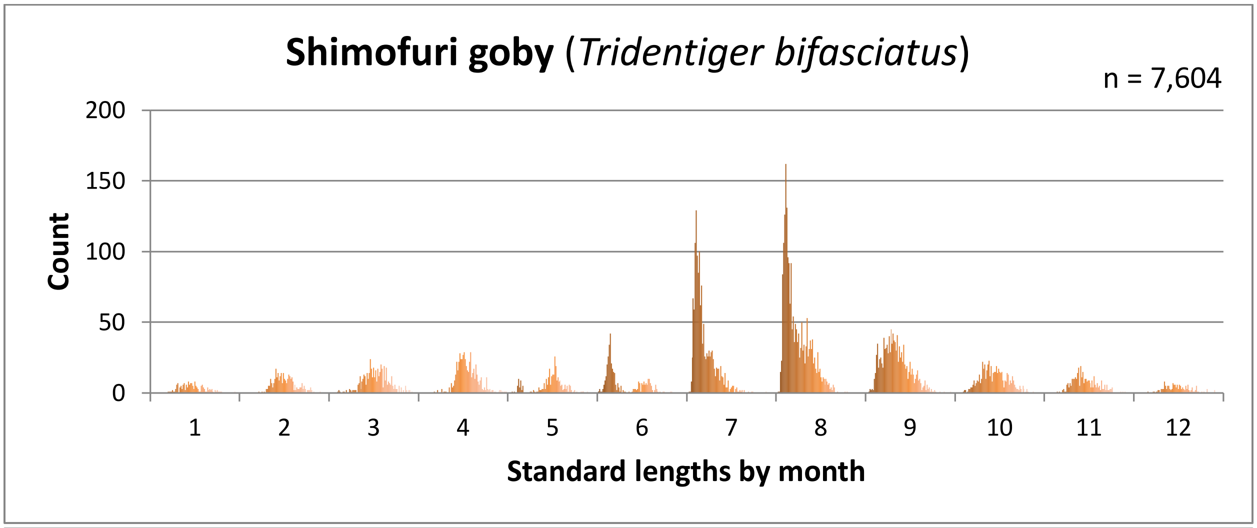
Year-class histograms (continued)

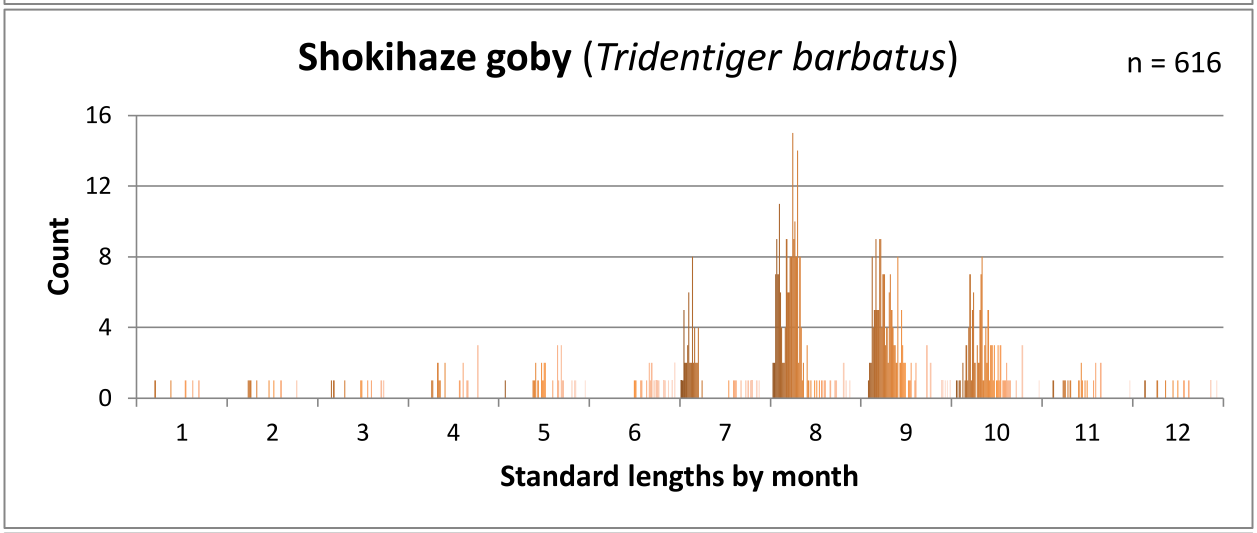


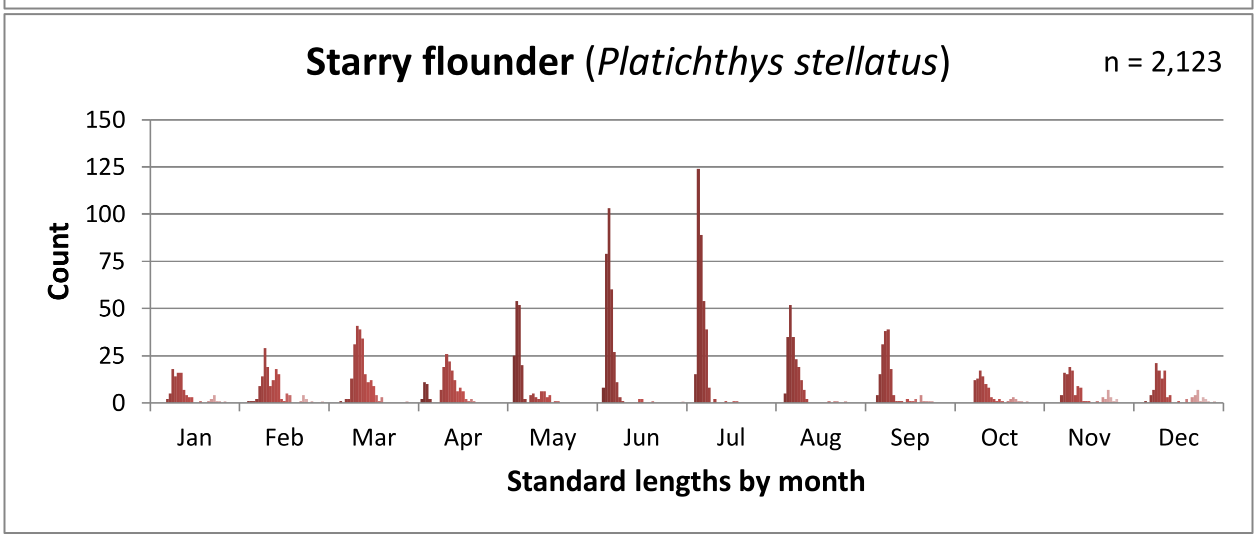




Year-class histograms (continued)







Appendix 4
Work flow - year classes

This appendix describes the process of delineating year-classes for fish species based on standard length and date of sample.

Step 1

Extract records necessary for examining year classes from tables in the Microsoft Access Suisun Marsh Fish database. Change species codes in "WHERE" statement as needed.

Example SQL query code:

```
SELECT Sample.SampleDate, Sample.SampleTime, Catch.OrganismCode, Catch.StandardLength,
Catch.Count, Sample.MethodCode, Sample.StationCode

FROM Sample INNER JOIN Catch ON Sample.SampleRowID = Catch.SampleRowID

WHERE (((Catch.OrganismCode)="SB" Or (Catch.OrganismCode)="TP" Or
(Catch.OrganismCode)="SKR" Or (Catch.OrganismCode)="CP" OR (Catch.OrganismCode)="ST"
Or (Catch.OrganismCode)="WCF"));

ORDER BY Catch.OrganismCode;
```

Step 2

Export Access table from step one (above) to a Microsoft Excel table.

Step 3

Create pivot tables and length frequency histograms in Excel

- Open table in Excel
- Separate data by species, creating a new Excel sheet for each species
- Create pivot tables for each species where columns are “Month,” rows are “Standard Length” and values are summed by “Sum of Count” (see appendix 2)
- In the pivot table, grouping by standard length measurements (groups of 2 or more mm) may be helpful for clarifying year-classes
- From pivot table, generate length-frequency histograms (see appendix 3)
- Manually determine breaks for fish year classes and note them with bars in the pivot table (see appendix 2)

Step 4

From breaks added to pivot table, create a new table in Access with minimum and maximum lengths by month for each species. See the year-class table attached in the supplemental materials section. This table supports queries involving year-classes of fishes.

Appendix 5

Work flow - map animations

This appendix describes the process of preparing catch and water quality data for mapping, creating maps, and converting maps to video.

Step 1

Extract relevant records from tables in the Microsoft Access Suisun Marsh Fish database.

To optimize performance, queries build on each other in several steps. Two tables were added to the database; one to enable year-class designations (AgesBySizeMo) and a second to allow preparation of records for spatial display (UCD_Fish_SampleSites_fullTable). These tables are attached as supplemental appendices.

<u>Subquery 1 SQL code (01_AgeClassQry):</u>

```
SELECT Catch.OrganismCode, Catch.Count, Sample.SampleDate,
DateSerial(Year([SampleDate]),Month([SampleDate]),1) AS AnimeDate, Sample.StationCode,
Sample.MethodCode, Catch.StandardLength, Month([SampleDate]) AS SampleMo,
Sample.SampleRowID, TrawlEffort.TrawlRowID, TrawlEffort.TowDuration,
UCD_Fish_SampleSites_fullTable.Status, UCD_Fish_SampleSites_fullTable.x_0402ft,
UCD_Fish_SampleSites_fullTable.y_0402ft

FROM ((UCD_Fish_SampleSites_fullTable INNER JOIN Sample ON
UCD_Fish_SampleSites_fullTable.Code=Sample.StationCode) INNER JOIN TrawlEffort ON
```

```sql
Sample.SampleRowID=TrawlEffort.SampleRowID) INNER JOIN Catch ON
Sample.SampleRowID=Catch.SampleRowID

WHERE (((Sample.SampleDate)>#12/31/1979#) AND ((Sample.MethodCode)="OTR") AND
((UCD_Fish_SampleSites_fullTable.Status)="Current"))

ORDER BY Sample.SampleDate, Sample.StationCode;
```

Subquery 2 SQL code (02_AgeClassQry):

```sql
SELECT [01_AgeClassQry].OrganismCode, [01_AgeClassQry].Count,
[01_AgeClassQry].SampleDate, [01_AgeClassQry].AnimeDate, [01_AgeClassQry].StationCode,
[01_AgeClassQry].MethodCode, [01_AgeClassQry].StandardLength,
[01_AgeClassQry].SampleMo, [01_AgeClassQry].TowDuration, (SELECT TOP 1
AgesBySizeMo.Class

FROM AgesBySizeMo

WHERE AgesBySizeMo.Month = [01_AgeClassQry].SampleMo AND
AgesBySizeMo.OrganismCode = [01_AgeClassQry].OrganismCode AND AgesBySizeMo.Min <
[01_AgeClassQry].StandardLength AND AgesBySizeMo.Max >=
[01_AgeClassQry].StandardLength) AS AgeClass, [01_AgeClassQry].SampleRowID,
[01_AgeClassQry].TrawlRowID, [01_AgeClassQry].x_0402ft, [01_AgeClassQry].y_0402ft

FROM 01_AgeClassQry;
```

Subquery 3 SQL code (03_AgeClassQry):

SELECT [02_AgeClassQry].AnimeDate, [02_AgeClassQry].SampleMo,

[02_AgeClassQry].StationCode, [02_AgeClassQry].AgeClass, [02_AgeClassQry].OrganismCode,

Sum([02_AgeClassQry].Count) AS SumOfCount, [02_AgeClassQry].TrawlRowID,

[02_AgeClassQry].TowDuration, [02_AgeClassQry].x_0402ft, [02_AgeClassQry].y_0402ft

FROM 02_AgeClassQry

WHERE ((([02_AgeClassQry].AgeClass) Is Not Null))

GROUP BY [02_AgeClassQry].AnimeDate, [02_AgeClassQry].SampleMo,

[02_AgeClassQry].StationCode, [02_AgeClassQry].AgeClass, [02_AgeClassQry].OrganismCode,

[02_AgeClassQry].TrawlRowID, [02_AgeClassQry].TowDuration, [02_AgeClassQry].x_0402ft,

[02_AgeClassQry].y_0402ft

ORDER BY [02_AgeClassQry].AnimeDate, [02_AgeClassQry].StationCode,

[02_AgeClassQry].AgeClass, [02_AgeClassQry].OrganismCode, [02_AgeClassQry].TrawlRowID;

Query SQL code for fishes map input (04_AgeClass_map_input):

SELECT [03_AgeClassQry].AnimeDate, [03_AgeClassQry].StationCode,

[03_AgeClassQry].AgeClass, [03_AgeClassQry].OrganismCode, Sum([03_AgeClassQry].SumOfCount) AS SumOfCount, Sum([03_AgeClassQry].TowDuration) AS SumOfTowDuration, Round(60*Sum([03_AgeClassQry].[SumOfCount])/Sum([03_AgeClassQry].[TowDuration]),1) AS FishPerHour, [03_AgeClassQry].x_0402ft, [03_AgeClassQry].y_0402ft

FROM 03_AgeClassQry

WHERE ((([03_AgeClassQry].AgeClass) Is Not Null))

GROUP BY [03_AgeClassQry].AnimeDate, [03_AgeClassQry].StationCode, [03_AgeClassQry].AgeClass, [03_AgeClassQry].OrganismCode, [03_AgeClassQry].x_0402ft, [03_AgeClassQry].y_0402ft

ORDER BY [03_AgeClassQry].AnimeDate, [03_AgeClassQry].StationCode, [03_AgeClassQry].OrganismCode, [03_AgeClassQry].AgeClass;

Subquery for invertebrates (03_InvertQry):

SELECT [02_AgeClassQry].AnimeDate, [02_AgeClassQry].SampleMo, [02_AgeClassQry].StationCode, [02_AgeClassQry].OrganismCode, Sum([02_AgeClassQry].Count) AS SumOfCount, [02_AgeClassQry].TrawlRowID, [02_AgeClassQry].TowDuration, [02_AgeClassQry].x_0402ft, [02_AgeClassQry].y_0402ft

FROM 02_AgeClassQry

GROUP BY [02_AgeClassQry].AnimeDate, [02_AgeClassQry].SampleMo,

[02_AgeClassQry].StationCode, [02_AgeClassQry].OrganismCode,

[02_AgeClassQry].TrawlRowID, [02_AgeClassQry].TowDuration, [02_AgeClassQry].x_0402ft,

[02_AgeClassQry].y_0402ft

HAVING ((([02_AgeClassQry].OrganismCode)="CRANGON" Or

([02_AgeClassQry].OrganismCode)="CORBULA" Or

([02_AgeClassQry].OrganismCode)="EXOPAL" Or

([02_AgeClassQry].OrganismCode)="MAEOTIAS" Or

([02_AgeClassQry].OrganismCode)="PALAEMON" Or

([02_AgeClassQry].OrganismCode)="MYSIDS" Or

([02_AgeClassQry].OrganismCode)="CORBICULA" Or

([02_AgeClassQry].OrganismCode)="HARISSMC"))

ORDER BY [02_AgeClassQry].AnimeDate, [02_AgeClassQry].StationCode,

[02_AgeClassQry].OrganismCode, [02_AgeClassQry].TrawlRowID;

Query SQL code for invertebrate map input (04_Invert_map_input):

SELECT [03_InvertQry].AnimeDate, [03_InvertQry].StationCode, [03_InvertQry].OrganismCode,

Sum([03_InvertQry].SumOfCount) AS SumOfCount, Sum([03_InvertQry].TowDuration) AS

SumOfTowDuration,

Round(60*Sum([03_InvertQry].[SumOfCount])/Sum([03_InvertQry].[TowDuration]),1) AS InvertPerHour, [03_InvertQry].x_0402ft, [03_InvertQry].y_0402ft

FROM 03_InvertQry

GROUP BY [03_InvertQry].AnimeDate, [03_InvertQry].StationCode, [03_InvertQry].OrganismCode, [03_InvertQry].x_0402ft, [03_InvertQry].y_0402ft

ORDER BY [03_InvertQry].AnimeDate, [03_InvertQry].StationCode, [03_InvertQry].OrganismCode;

Query SQL code for water quality parameters (06_WQ_Averages)

SELECT Sample.SampleDate, DateSerial(Year([SampleDate]),Month([SampleDate]),1) AS AnimeDate, Sample.StationCode, Round(Avg(Sample.WaterTemperature),2) AS AvgOfTemp, Round(Avg(Sample.Salinity),2) AS AvgOfSalinity, Round(Avg(Sample.SpecificConductance),2) AS AvgOfSpCond, Round(Avg(Sample.DO),2) AS AvgOfDO, Avg(Sample.Secchi) AS AvgOfSecchi, UCD_Fish_SampleSites_fullTable.x_0402ft, UCD_Fish_SampleSites_fullTable.y_0402ft

FROM (StationsLookUp INNER JOIN UCD_Fish_SampleSites_fullTable ON StationsLookUp.StationCode = UCD_Fish_SampleSites_fullTable.Code) INNER JOIN Sample ON StationsLookUp.StationCode = Sample.StationCode

WHERE (((UCD_Fish_SampleSites_fullTable.Status)="Current"))

GROUP BY Sample.SampleDate, Sample.StationCode,

UCD_Fish_SampleSites_fullTable.x_0402ft, UCD_Fish_SampleSites_fullTable.y_0402ft,

UCD_Fish_SampleSites_fullTable.Code, StationsLookUp.StationCode

HAVING (((Sample.SampleDate)>#12/31/1979#))

ORDER BY Sample.SampleDate, UCD_Fish_SampleSites_fullTable.Code;

Step 2

Run queries and export the resulting tables, listed below, to text or Excel files:

04_AgeClass_map_input

04_Invert_map_input

06_WQ_Averages

Step 3

Import "04_AgeClass_map_input" and "04_Invert_map_input" text files to the ESRI ArcGIS environment and convert them to spatial data. These instructions are for operations in ArcGIS version 10.2.

- Add prepared tables to ArcMap

- Right-click and use “Display XY Data…” function to designate latitude and longitude values from the x_0402ft and y_0402ft columns in the table. Values in these columns are in the California State Plane Zone II (feet) projection.
- Export spatially enabled tables to shapefiles and add the shapefiles to the map.

The “06_WQ_Averages” file requires different handling because null fields exist in the water quality data columns. ArcMap fills null fields with “0” during the import process, which is not appropriate. To avoid this, import the text file to MS Excel and create a separate tab for each water quality parameter, deleting other water quality columns but retaining all date, site, and coordinate data. Sort by the water quality parameter of interest in each tab and delete all rows with null values.

To convert point water quality data to polygons, import each Excel sheet to ArcMap, designate latitude and longitude with values from the x_0402ft and y_0402ft columns, export spatially enabled tables to shapefiles, then perform a spatial join between each of the water quality parameter point files and a polygon file with features including sections of sloughs that overlap points; one slough section per point.

- Make sure points fall within bounds of slough polygons and, if any points fall outside slough bounds, relocate them using the Editor tool.

- Perform a one-to-many join where the target layer is the slough polygons and the join layer is the water quality file. “Keep All Target Features” should be checked. Join features that intersect spatially. Repeat for each parameter.

Step 4

For fish and invertebrate data, sequentially export records for each species (and year-class, when appropriate) to stand-alone shapefiles. In order to display more than one species together in an animation, files must be separate so that symbology can be set for each one.

Step 5

Generate base maps and set up animations

- Symbolize each species and species year-class proportionally by catch per unit effort
- Assign variable colors for species with year-class breaks
- Enable time on desired layer(s)
- Export animation frames as JPEG image files

Step 6

Create videos

- Assemble final maps from JPEGs with video editing software
- Export to stand alone video format

Appendix 6

Methods for estimating the effect of Suisun Marsh Salinity Control Gate operation on salinity in Montezuma Slough

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July 2014

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UC Davis Center for Watershed Sciences

The Suisun Marsh Salinity Control Gates (SMSCG) are designed to reduce salinity in Montezuma Slough, a channel connecting the Sacramento San Joaquin Delta confluence to Grizzly Bay. Gate operations take advantage of tidal energy to increase fresh water flow from the Delta confluence through Montezuma Slough and into the interior of Suisun Marsh. Ideally, the SMSCG are either totally open or in operation, but gate conditions frequently vary from these two states. The purpose of this report is to quantify the relative effect of the different gate operations on salinity in Montezuma Slough.

As the stop logs have two operating states (in and out) and the gates have three operating states (open, closed, and operating), the structure has a total of six possible states of operation. In viewing the records of operation (DWR 2014), the SMSCG have been configured in all six operation states. Each of these six states has different effects on the salinity concentration in Montezuma Slough.

The results in figure 1 show that the operations of the gates reduce the overall salinity in Suisun Marsh. The pink line corresponds to salinity when the gates are open and the stop logs are out. The spatially averaged salinity of Montezuma Slough is 12.86 mmhos/cm in this condition. When the gates are in operation and the stop logs are in, the spatially averaged salinity reduces to 9.52 mmhos/cm, as shown with the blue line. It is assumed that the salinity of the slough is equal to the salinity of Grizzly Bay (18 mmhos/cm) when the stop logs are in and the gates are closed.

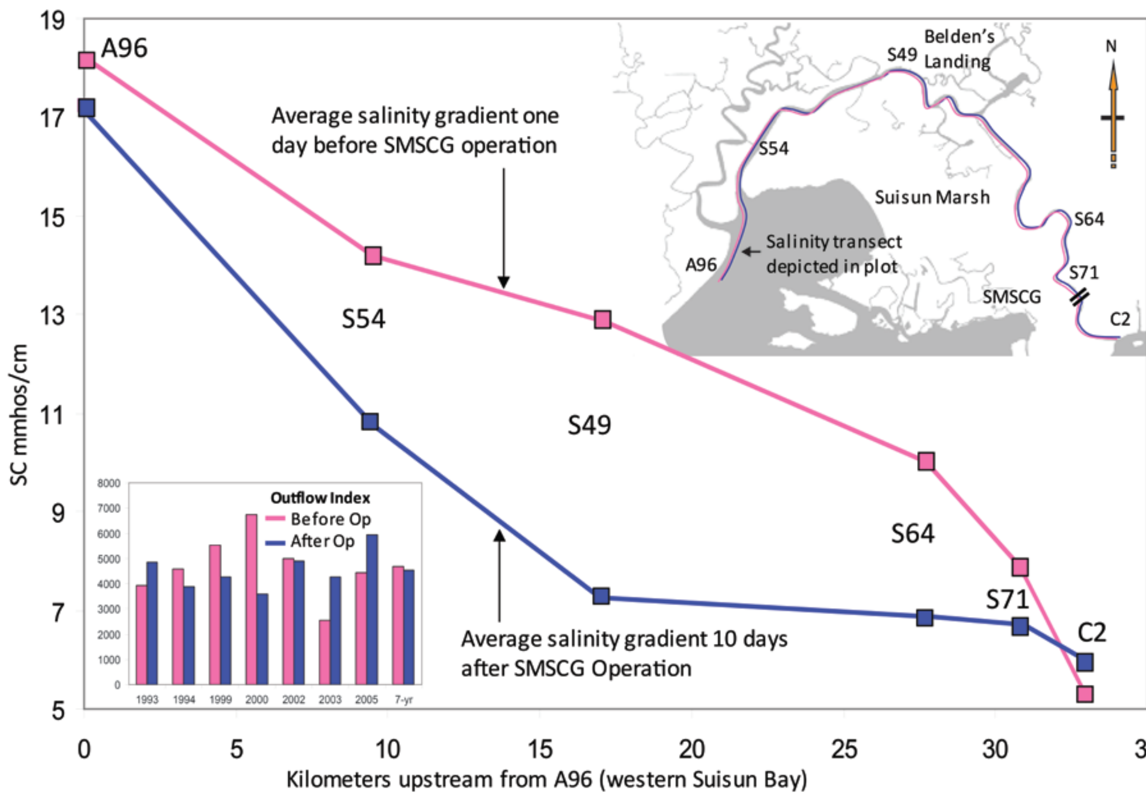

Figure 1. Suisun Marsh Salinity Control Gate effect on salinity concentrations in Montezuma Slough (Enright 2014)

The effects from the other three states of operation are determined by assuming that the amount of channel constriction caused by the gates is proportional to flow resistance at that point in the slough. An increased value in resistance means that less of the fresh water will enter Montezuma Slough from the Delta confluence. This reduction of input from the Delta confluence is compensated for with an increased input of more saline water from Grizzly Bay. For example, when the stop logs are in and the gates are open, the channel width is 68% of its “natural width”. This sudden 38% reduction in channel width is considered an increase in channel resistance by 38%. A 38% increase in resistance results in a reduction of flow through the control gates by 38%. Thus, to maintain conservation of mass, the decrease in input from the Delta confluence is accounted for by an equally increased input from Grizzly Bay. If we assume that the salinity concentration entering the slough from the Delta confluence and Grizzly Bay are 5 mmhos/cm and 18 mmhos/cm, respectively, we can calculate the salinity of the slough and compare this value against the “natural conditions” (when the stop logs are out and the gates are open).

Table 1. Effects of SMSCG at different operation states (pre-2004 NOAA fisheries agreement)

Stop Logs	Gates	Salinity (mmhos/cm)	Difference (%)	Rel. Value	Status
IN	O	14.78	-15%	63	Constricted Flows
IN	Op	9.52	26%	165	Freshwater inputs
IN	C	18	-40%	0	All flows are blocked
Out	O	12.86	-	100	Natural flows
Out	Op	10.77	16%	141	Semi-Freshwater input
Out	C	16.02	-25%	39	Constricted Flows

Table 1 shows the six operational states of the SMSCG and the estimated salinity of the slough as a result of those operations. The percent differences are all with respect to the slough in "natural conditions". The relative value column represents proportional values of the influence of the SMSCG. For scaling, the natural flows (stop logs out and gates open) and the blocked flows (stop logs in and gates closed) were set to 100 and 0, respectively. So a 40% difference from “natural flows” results in a change of 100 in relative value. The rest of the values in the column are calculated based on that relationship. An IEP newsletter indicated that the boat locks accounted for 7% of flow through the SMSCG (Vincik 2002). So, the relative values of the SMSCG after the National Oceanic and Atmospheric Association (NOAA) fisheries agreement (NOAA 2004) were determined by reducing the difference between an operation state and the natural state by 7%.

Table 2. Effects of SMSCG at different operation states with relative values adjusted as per NOAA Fisheries Agreement.

Stoplogs	Gates	Rel. Value
IN	O	65
IN	Op	160
IN	C	7
Out	O	100
Out	Op	138
Out	C	43

The relative values provide an estimate of the proportional effect of the SMSCG on salinity in Montezuma Slough. It should be noted that some assumptions were made to ease the calculations. If two of the gates were in the same operational state, but one was not, it was assumed that the operational state of the single gate was negligible and that the operational state of the two gates best reflected the gates portion of the SMSCG. Also, for ease of calculations, constriction of the gates was assumed to be directly proportional to the resistance.

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