Life History Conceptual Model for North American Green Sturgeon (*Acipenser medirostris*)

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PREFACE

This Conceptual Model is part of a suite of conceptual models which collectively articulate the current scientific understanding of important aspects of the Sacramento-San Joaquin River Delta ecosystem. The conceptual models are designed to aid in the identification and evaluation of ecosystem restoration actions in the Delta. These models are designed to structure scientific information such that it can be used to inform sound public policy.

The Delta Conceptual Models include both ecosystem element models (including process, habitat, and stressor models) and species life history models. The models were prepared by teams of experts using common guidance documents developed to promote consistency in the format and terminology of the models http://www.delta.dfg.ca.gov/erpdeltaplan/science_process.asp .

The Delta Conceptual Models are qualitative models which describe current understanding of how the system works. They are designed and intended to be used by experts to identify and evaluate potential restoration actions. They are not quantitative, numeric computer models that can be "run" to determine the effects of actions. Rather they are designed to facilitate informed discussions regarding expected outcomes resulting from restoration actions and the scientific basis for those expectations. The structure of many of the Delta Conceptual Models can serve as the basis for future development of quantitative models.

Each of the Delta Conceptual Models has been, or is currently being subject to a rigorous scientific peer review process. The peer review status of each model is indicated on the title page of the model.

The Delta Conceptual models will be updated and refined over time as new information is developed, and/or as the models are used and the need for further refinements or clarifications are identified.

CONTENTS

I. Introduction

The purpose of this report is to develop a conceptual life history model of North American green sturgeon (*Acipenser medirostris*) and the factors that affect reproduction, growth, and survival in the Sacramento and San Joaquin rivers and San Francisco Bay-Delta. This model can be used to organize, visualize, and evaluate how the complex life history of green sturgeon relates to the spatial and temporal variability of riverine and estuarine ecosystems and potential consequences of ecosystem restoration and water management alternatives. This model is compatible with the suite of environmental and species models developed by the Department of Fish and Game Ecosystem Restoration Program (ERP) to assess and prioritize proposed restoration actions for the Delta. The model has a geographic emphasis on the Sacramento River and Bay-Delta regions, though the entire distribution of green sturgeon must be considered when population level responses are of concern, due to the unique, highly-migratory life history of this species.

The conceptual life history model incorporates information from numerous sources about green sturgeon, often relying upon life history information from populations outside the Southern Distinct Population Segment (DPS) and occasionally considering information from the sympatric white sturgeon (*A. transmontanus*). While surrogate information from other North American sturgeon could have been used in the model, the distinctive anadromous and ecological characteristics of green sturgeon limited the utility of these species' information. Due to the limits of quantitative information about green sturgeon, this model is presented in a qualitative narrative with numerical information provided, when available. While it will not provide quantitative limits on species take relative to maintaining a stable population size, it could be further developed into a population forecasting model since it divides the life history into life history stages, transition probabilities, and factors whose affects on reproduction and survival could be quantified.

Life history stage transitions are visualized in a series of life stage submodels highlighting the processes and relationships among ecological factors influencing the transition between stages (Figures 1 and 2). A complex set of conditions and processes are necessary to determine whether an individual fish completes the transition from one life stage to the next. Our knowledge of green sturgeon life history remains limited as to the relative importance of biotic and abiotic factors critical for maintaining self-sustaining populations of green sturgeon. Thus, the importance, predictability, and understanding of each of these linkages are identified in the model. Lastly, a similar characterization of independent stressors is undertaken to describe potential factors affecting survival during each life history stage in a known geographic region. This model is dynamic and not intended to be a final version. As new information becomes available, the model should be refined so managers and biologists have the most current information available.

II. Biology (Figure 3, Table 1)

Green sturgeon (*Acipenser medirostris*) are long-lived, anadromous fishes, which begin their lives in the upper and middle segments of the largest subbasins flowing into the Sacramento River and San Francisco Bay-Delta (Figures 3, 5). Eggs, larvae, and juveniles showed distinct tolerances of temperature, dissolved oxygen, light, and salinity in experiments (Table 1). Eggs and milt are released in turbulent water above deep, complex habitats where they drift and stick onto the substrate. Eggs require constant, cool water temperatures and hatched after approximately a week as finless larvae in experiments while non-optimal temperatures affected embryonic development in experiments (Deng et al. 2002, Linares-Casenave et al. in preparation). Larval sturgeon required cool water temperatures and high dissolved oxygen levels while digesting their yolk sac prior to feeding on their own (Gisbert et al. 2001, Van Eenennaam et al. 2005). Once feeding, larvae initiate a 12-day nocturnal emigration in experiments (Kynard et al. 2005) and larval metamorphosis is completed after approximately 45 days (63-94mm, Deng et al. 2002). Larval and riverine juvenile green sturgeons are bottom-oriented and nocturnally active until a few months of age (Kynard et al. 2005).

Juvenile green sturgeon are tolerant of warmer temperatures, which influences growth and behavior (Allen et al. 2006b). High dissolved oxygen levels are required by juvenile green sturgeon for respiration and to avoid chronic stress (Lankford et al. 2003, Mayfield and Cech 2004). During the day, juveniles selected low light habitats and were primarily inactive, while they seemed to forage actively during night in experiments (Kynard et al. 2005). Juvenile green sturgeon migrate into seawater portions of natal estuaries as early as one and a half years old (75cm TL, Allen and Cech 2007), and eventually emigrate to nearshore coastal waters by three years old. Green sturgeon returning to the Klamath River grew to 300mm in their first year and 600mm within the first 2-3 years of their life (Nakamoto et al. 1995), though the riverine and estuarine conditions in this system are distinctly different from the Sacramento River and Bay-Delta. Subadults are migratory, spending their next 12-16 years foraging in the coastal ocean and entering western estuaries during the summer (Moser and Lindley 2007). In the ocean, green sturgeon inhabit the coastal shelf out to 100m depth with occasional, rapid vertical ascents near or to the surface (Erickson and Hightower 2007).

Reproductive adults migrate southward back to rivers in late winter and early spring to spawn between late March and late July (Benson et al. 2007, Heublein et al in press). Younger and smaller adult age classes are dominated by male green sturgeon, while older and larger age classes are dominated by females on the Klamath and Rogue rivers, presumably due to the earlier maturity and shorter life span of males (Erickson and Webb 2007, Van Eenennaam et al. 2006). It is presumed age structuring is similar in the Southern DPS. Green sturgeon can reach up to 270cm with a maximum age of 60-70 years old, though fish greater than 200cm are uncommon (Moyle et al. 2002, Skinner 1962, Emmett et al. 1991). Based on adult spawning behavior and habitat suitable for green sturgeon embryo development, it seems likely reproductive females select spawning areas with turbulent, high velocities near low velocity resting areas. Green sturgeon spawning areas are presumed to be characterized by larger substrates upstream of lower gradient reaches, which usually have slower velocities.

Adults spawn over a short period within a week, and no atretic females (individuals undergoing reabsorption of eggs instead of releasing them) have been observed in spawning populations, suggesting females spawn regardless of physical conditions in spawning habitats. The eggs of a single female are fertilized by the sperm of multiple males. After spawning, adults move downstream into holding habitats in the lower river or further into the Delta, returning through the San Francisco Bay to the ocean during late fall or winter (Heublein in press). Individuals then migrate northward and return to spawn every two to four years (Erickson and Webb 2007, Lindley et al. 2008). Species fecundity peaks around 24 years old, when all females in this age cohort have matured (Beamesderfer et al. 2007).

A. Distribution (Figure 4, Table 2)

Population structure: Green sturgeon range from Ensenada, Mexico to the Bering Sea, Alaska (Colway and Stevenson 2007, Moyle 2002). Green sturgeons are currently known to spawn in two large California basins- Sacramento and Klamath rivers (Figure 4). These reproducing populations are genetically distinct and occupy the Southern and Northern Distinct Population Segment, respectively (Adams et al. 2002, Israel et al. 2004). Long term populations trends show adult populations in the less-altered Klamath and Rogue rivers are fairly constant with a few hundred spawning adults typically being harvested annually by tribal fisheries. The green sturgeon population in the Sacramento River is believed to have declined over the last two decades with less than 50 spawning green sturgeon being sighted annually in the best spawning habitat along the middle section of the Sacramento River (Richard Corwin, Bureau of Reclamation (BOR), Pers. Comm.). In the Umpqua, Feather, Yuba, and Eel rivers green sturgeon sightings are extremely limited and spawning has not been recently recorded. In the San Joaquin and South Fork Trinity rivers, the green sturgeon population appears extirpated.

Eggs, Larvae, Young-of-the-Year: Egg and larval green sturgeon are confined to freshwater portions of the Sacramento River mainstem (Table 2). Eggs are incubated in immediate proximity to spawning areas between Anderson and Hamilton City due to their limited mobility. Modeled temperatures are below 18°C until after the spawning season above Colusa (Orlob and King 1997), and temperature loggers demonstrate these temperatures are attained as far downstream as the Irvine Finch River Access (Rkm 398) until the end of the spawning seasons (P. Klimley, UCD, unpublished data). Eggs have been captured upstream of Red Bluff Diversion Dam (RBDD) in the Massacre Flats pool, below Red Bluff Diversion Dam, and below the confluence of Antelope Creek between April and July (B. Poytress, US Fish and Wildlife, Pers. Comm.). Larval green sturgeons disperse from nursery habitats quickly, but then slow their emigration. In the Sacramento River, larval and juvenile green sturgeon are encountered in rotary screw traps at Red Bluff Diversion Dam between early May and mid-August and in rotary screw traps at the Glenn-Colusa Irrigation District pumping plant between early May and October (Adams et al. 2002); Table 3).

On occasion, juvenile green sturgeon older than one year-old are observed in the RBDD and GCID rotary screw traps often during winter or early spring. Allen and Cech (2007) observed that young-of-the-year green sturgeon could tolerate brackish waters as early as three months past hatch in experiments. While little is actually known about the distribution of habitat and movement young-of-the-year and riverine juvenile green sturgeon, observations suggest that they are distributed in the mainstem below Anderson and in fresh and brackish portions of the north and interior Delta. Green sturgeons use these areas to forage and rear until they gain the osmoregulatory capacity to tolerate higher salinity concentrations.

Juveniles: Though green sturgeon are believed to not enter the ocean and reside in freshwater and brackish environments for up to three years, juveniles survived in seawater as early as the end of their first year (Allen et al. 2006a, Allen et al. 2006b). Juveniles use riverine, subtidal, and intertidal habitats along the lower Sacramento River and many areas of the Bay-Delta. Juvenile green sturgeon have been captured at Red Bluff Diversion Dam and more frequently at the Glenn Colusa Irrigation District's pumping plant indicating potential rearing of more than one age class in the upper and middle Sacramento River. There are no records of juveniles from bypasses along the lower Sacramento River or its tributaries, including the Feather or Yuba rivers. California Department of Fish and Game (CDFG, 2002) reported 61 juvenile and subadult green sturgeon (20-112cm) captured during the San Francisco Bay Outflow Study between 1980-2001, with a majority of individuals captured between April and October. These fish were captured in the following locations (CDFG 2002): South San Francisco Bay (3), Central San Francisco Bay (6), San Pablo Bay (10), Suisun Bay (21), and the Delta (14). Data from the California Department of Fish and Game sturgeon report card found anglers captured juvenile green sturgeon between Rio Vista and Chipps Island, Sacramento Deepwater Ship Channel, Montezuma Slough, Napa River, Carquinez Strait, and Suisun Bay (Gleason et al. 2007). Juvenile green sturgeon were captured during the summer in shallow shoals (1-3 m deep) in the lower San Joaquin River (Radtke 1966). Juvenile green sturgeon were observed in Clifton Court Forebay between November 2002 and March 2003 (CDFG 2002). Young-of-the-year juveniles are caught at the state and federal fish pumps in the South Delta between March and December.

Subadults and adults: Coastally migrant subadult green sturgeon tagged by the California Department of Fish and Game have been recaptured off Santa Cruz, California, in Winchester Bay on the Southern Oregon coast, at the mouth of the Columbia River, and in Gray's Harbor (Chadwich 1959, Miller 1972). Lindley et al. (2008) observed fish tagged with individually coded ultrasonic beacons in some of these locations also returned to San Francisco Bay, where they were recorded by tag detecting monitors. A study of 682 individual green sturgeon used genetic-based mixed stock analysis to assess the presence of Sacramento River green sturgeon in western estuaries. A majority of samples in collections from the Winchester Bay, OR, Columbia River, WA and Willapa Bay, WA were Sacramento River green sturgeon (Israel et al. submitted). A significant number of fish collected in Grays Harbor, WA were also of Sacramento River origin (Israel et al. submitted). Within coastal migrant and adult collections of fish from San Pablo Bay and Suisun Bay, practically all green sturgeon were from the Sacramento River, suggesting green sturgeon migrate primarily north of their natal rivers (Lindley et al. 2008).

Within the Bay-Delta, subadults and adults are encountered during California Fish and Game surveys during the all seasons. During summer and fall, they are principally found in San Pablo, but also in Suisun Bay (Nina Kogut, California Dept. of Fish and Game, Pers. Comm.). During the winter and spring, reproductively mature green sturgeons enter San Francisco Bay-Delta and migrate up the Sacramento River. Ultrasonically-tagged green sturgeon are recorded at detection monitors situated above Hamilton City and the vicinity above Red Bluff Diversion Dam during the spring and summer (Heublein et al. in press) yet, adult green sturgeon are rarely observed by CDFG in spring fyke net traps near Knight Landing (CDFG 2002). Subadult and adults sturgeon are incidentally observed by fishers and biologists in the lower Feather and Yuba rivers in the summer, though recent sightings are extremely limited. Subadult and adult green sturgeon are rarely observed in monitoring on the Yolo Bypass (Zoltan Matica, Department of Water Resources, Pers. Comm.), since this area is rarely inundated and connected to the Sacramento River while these fish are in the lower Sacramento River area. They have been observed in the South Delta in winter and spring (CDFG 2002), with no recent observation of fish residing in the San Joaquin River.

Spawning: In the Sacramento River, spawning is presumed to occur in the mainstem from the confluence of Battle Creek (Rkm 438) to the area upstream of Los Molinos. When high outflows are sustained into the early summer, green sturgeon may also enter the lower Feather and Yuba rivers. A review of green sturgeon fork length from RBDD and GCID (CDFG 2002) suggests that larvae occur in both areas during the same period, and thus reproduction likely occurs below RBDD closer to GCID during some years.

III.Ecology (Figures 5-11)

A. Reproduction to embryonic development (Figure 6)

Optimal conditions for spawning are presumably found at many locations within the upper Sacramento River. Temperatures between 17-18°C are the upper limit of thermal optima for green sturgeon embryos, while greater temperatures affected development and hatching success (Van Eenennaam et al. 2005). Temperatures greater than 23°C led to complete mortality before hatch (Van Eenennaam et al. 2005). Flow relationships for white sturgeon have been examined by DFG (Kohlhorst et al. 1991), but not for green sturgeon. A flow relationship for green sturgeon is presumed to be similar to white sturgeon with greater young-of-year production resulting from greater flows during the spawning season between April and July (Kohlhorst et al. 1991). Kohlhorst et al. (1991) explored association between white sturgeon year class strength and mean daily freshwater outflow from the estuary, mean daily freshwater diversions from the delta, and mean daily percent of inflow diverted. Recruitment was significantly positively correlated with outflow in all months from April to July, but not mean daily volume of diversions. Kohlhorst et al. (1991) also found a recruitment pattern that seemed influenced by spawning stock abundance for white sturgeon which matures at about 14 years of age, and it is likely spawning stock abundance and environmental factors both influence recruitment of sturgeon young-of-year. The estimated number of green sturgeon contributing to juvenile samples collected at Red Bluff Diversion Dam between 2002 and 2006 increased with greater flows at Bend Bridge (Israel 2007). This increased spawning success may be due to higher flows that increase turbulence in optimal spawning habitats, which may increase fertilization rates or may be due to more reproductive individuals reaching optimal spawning habitats.

B. Developing embryo to feeding larvae (Figure 7)

Water temperature affects the survival of early life stages of green sturgeon. Green sturgeon spawning occurs between April and July, which is a period of regulated flows in Sacramento and Feather rivers. Water temperatures, which are principally a function of water quantity and air temperature, can fluctuate significantly due to managed releases from large reservoirs in both subbasins. Temperature may be a limiting factor for annual recruitment, if not enough green sturgeon are able to migrate far enough upstream to spawn in areas that permit successful dispersal of eggs and larvae into reaches favorable to survival of these life stages. Temperature affects the following critical processes: 1) hatching rates, 2) rate and type of embryonic development, and 3) survival (Van Eenennaam et al. 2005, Werner et al. 2007). An increased number of embryos developed abnormalities between 17.5° and 22°C and the length of hatched embryos decreased at these upper temperatures in experiments (Linares-Casenave et al. in preparation). When water temperature was experimentally reduced from 26°C after three days to 17°C, a significant number of larvae appeared to recover from their deformities in experiments (Werner et al. 2007). While green sturgeon may survive incubation at the limits of their temperature optimum, reproductive success and young-of-year recruitment are presumably negatively impacted when embryos and larvae are exposed to temperatures greater than 20°C

Green sturgeon larvae oxygen consumption increased five-fold while they absorbed nutrients in their yolk sacs (Gisbert and Doroshov 2001). Ambient dissolved oxygen levels have a significant role in survival of larvae, since fin development is incomplete at this stage and they are poor swimmers that cannot move more than a few centimeters (Kynard et al. 2005). Green sturgeon remain in habitats with some type of cover until they develop into larvae (Kynard et al. 2005). The percent of loss of life among larvae exposed to different experimental substrates was significant. Mortality of larvae was highest (40%) in cobble substrate compared to sand (11%), slate-rocks (7%), and glass (0%) (Nguyen and Crocker 2007). Also in this experiment, the larvae in the flat-surfaced treatments had higher specific growth rates. Striped bass, suckers and pikeminnow are often observed downstream of spawning green sturgeon at RBDD (J. Israel, Pers. Observation) and are likely predating upon eggs. Egg predation has not been quantified, and its effect on mortality relative to temperature and dissolved oxygen is unknown.

C. Feeding larvae to juveniles (Figure 8)

Larvae must quickly switch from feeding on their yolk reserves to the ingestion of prey items. This rapid initiation of exogenous feeding by larvae is critical. In experiments, larvae deprived of food exhibited a progressive deterioration underway after five days of starvation, and necrosis of larvae was observed at 10-15 days of starvation (Gisbert and Doroshov 2003). The growth of post-yolk-sac fish (~0.1-10g) to juvenile green sturgeon appeared temperature independent when growth was measured between 19 and 24ºC (Allen et al. 2006b). Specific growth rates, wetted weight, and total lengths were greater at temperatures >24ºC and a cycling temperature of 19-24ºC than at a constant temperature of 19ºC due to increases in food consumption. Thus, is seems elevated and cycling temperature do not have adverse effects on juveniles if food is abundant and dissolved oxygen is available. Post-migrant larvae and early juveniles forage both during day and night with a nocturnal activity peak (Kynard et al. 2005). No studies have been undertaken to identify food resources for larval green sturgeon. However, larvae and young-of-year of the shovelnose sturgeon feed principally on Diptera and Ephemeroptera pupae and larvae (Braaten et al. 2007).

Riverine juvenile green sturgeon increased their swimming performance at an elevated temperature of 24°C compared to 19°C in experiments. Hence, it is possible that these fish can perform at increased activity levels in warmer summer river temperatures. Juveniles between 110-181 days past hatch dph were observed to move downstream nocturnally until water temperatures decreased to about 8ºC (Kynard et al. 2005). Juvenile green sturgeon of a mean age of 150 dph, which were saltwater tolerant had a decreased swimming performance (Allen et al. 2006a). Among three age groups (100 dph, 170 dph, 533 dph); when acclimated to saltwater only the youngest fish died at a rate of 23%. Juvenile green sturgeon develop critical osmoregulatory capacities between their first and second year that permit them to enter saltwater at a size of 75cm and length of 1.5kg (Allen and Cech 2007). There is no difference in oxygen consumption rates between salinity treatments or age groups, indicating the energetic costs of living in a particular environment at a particular age were not prohibitively high (Allen and Cech 2007). In this experiment, oxygen consumption in the lab ranged from 61 to 76 mg $O_2 hr^{-1} kg^{-1}$, with a trend of increasing oxygen consumption with body mass. A positive correlation existed between swimming performance and small body size and seawater intolerance (Allen et al. 2006a). This relationship became negative at sizes larger than 25cm, once green sturgeon were 100% seawater tolerant. Allen et al. (2006a) documented morphological features such as larger relative pectoral fin surface area and behavioral features such as rostrum wedging and pectoral fin holding were observed suggestive of holding in a riverine environment (Allen et al. 2006a). This adaptation may increase the availability of riverine habitats for foraging to young-of-the-year green sturgeon.

D. Juveniles to coastal migrant (Figure 9)

Our understanding of juvenile habitat is poorly understood. Juvenile green sturgeons inhabit the Sacramento River and San Francisco Bay-Delta. In the river, they occupy low-light habitats with some rock structure during their first winter. Juveniles have been reported to forage at night, while seeking the darkest available habitats during the day (Kynard 2005). Juvenile green sturgeon do have morphological and behavioral attributes for holding in flowing riverine environments (Allen et al. 2006a). In the estuary, it is possible that older juvenile green sturgeon are capable of moving across highly variable physical gradients in salinity, temperature, dissolved oxygen as are adults in the ocean environment (Kelly et al. 2007, Moser and Lindley 2007). Kaufman et al. (2006) found the oxygen binding of green sturgeon juveniles appeared to have low temperature sensitivity, which would permit fishes to bind sufficient oxygen with increased water temperatures. The oxygen binding and uploading responses of juvenile green sturgeon across a range of temperatures between 11° and 24° C suggests they are capable of inhabiting slightly hypoxic-environments (e.g., when compared to that of rainbow trout) while maintaining moderate aerobic activity (Kaufman et al 2006). These experimental data also suggested green sturgeon have a limited ability to handle increased environmental CO_2. Flow may indirectly influence juvenile foraging and survival by modifying the availability of freshwater and low-salinity habitats in the Delta and Suisun Bay during green sturgeon's first year of life.

Very little is known about the growth and swimming capacity of green sturgeon in estuarine and saltwater environments. Larger young-of-the-year and one year-old juvenile green sturgeon of 150-851g are found in these environments. Experimental research in freshwater conditions demonstrated green sturgeons can have rapid growth rates and high oxygen consumption rates relative to other sturgeon species (Mayfield and Cech 2004). Their consumption of food, growth, and food conversion efficiency generally increased with temperature between 11°C and 15°C, but stayed constant between 15° C and 19° C. Oxygen consumption, activity rate, and ventilatory frequency generally increased, while swimming performance decreased with temperatures from 19° to 24° C (Mayfield and Cech 2004). Juvenile green sturgeon likely seek areas with saturated levels of dissolved oxygen, since temperatures in this non-optimal range are likely encountered during the summer and into the early fall in the lower Sacramento River and Delta. Green sturgeon bioenergetic performance was optimal between 15° C and 19° C, regardless of feeding to food availability. Once juveniles have the capacity to live in saltwater, they are believed to spend one to three years in estuaries before making an initial ocean migration. These estuarine juveniles are believed to grow as large as 90 cm based on aging of pectoral fin rays (Nakamoto et al. 1995) and observations of fish at the federal and state pumping facilities (CDFG 2002).

The diet of riverine juvenile green sturgeon is unknown, though they are presumed to be generalists and opportunists. They presumably feed upon similar prey as other sturgeons. Seasonally abundant drifting and benthic invertebrates have been shown to be the major food items of shovelnose and pallid sturgeon on the Missouri River (Wanner et al. 2007), lake sturgeon in the St. Lawrence (Nilo et al. 2006), and white sturgeon in the lower Columbia (Muir et al. 2000). These seasonally abundant insects included Diptera, Ephemeroptera, and Tricopteran pupae and larvae. As sturgeons grow, the begin to feed on oligochaetes, amphipods (*Corophium sp.*), smaller fish, and fish eggs as represented in the diets of lake sturgeon (Nilo et al. 2006), pallid sturgeon (Gerrity et al. 2006), and white sturgeon (Muir et al. 2000). The diversity of the prey of sturgeons in rivers may be an indication of competition with other riverine fish for drifting prey. If this is the case, there may be competition for food with other fish present in the Sacramento River such as Sacramento suckers, striped bass, and salmonids. When juvenile green sturgeon enter the estuary, their diet shifts to larger benthic food items, though they remain generalists and opportunists. Mysid shrimp and amphipods (*Corophium*) were observed to be the primary food items in juvenile (<57cm) green sturgeon stomachs (Radtke 1966). Available benthic food items have changed during the recent past, and invasive Corbula has replaced native mollusks and shrimps. It is possible, this shift has led to dietary dilution, increased bioaccumulation of contaminant, and/or reduced growth of green sturgeon occupying the estuary, although the importance of this shift is unknown for green sturgeon.

E. Maturation of coastal migrants to spawning adults (Figure 10)

Subadults and adults inhabit the San Francisco Bay-Delta, Pacific Ocean, and estuaries in the Pacific Northwest. Reproductively mature adults migrate up the Sacramento River. In San Francisco Bay, coastal migrants were tracked in the San Francisco, San Pablo, and Suisun bays (Kelly et al. 2007). In these regions, they occupied areas of depths from 0 to >10 meters, where there appeared to be no preference for temperature (14.5º to 20.8ºC), salinity (8.8 to 32.1 ppt), or dissolved oxygen (7 to 9 O_2 l^{-1}). Green sturgeon occupied estuaries in Washington State when estuarine water temperatures exceeded coastal water temperatures by at least 2ºC (Moser and Lindley 2007). In Willapa Bay, green sturgeon were exposed to rapid tidally influenced fluctuations in salinity up to 1 PSU $h^{-1}$and temperature of up to 2º C h^{-1}. They did not migrate due to patches of fresh waters or freshets (Moser and Lindley 2007). Subadult green sturgeon occupied Willapa Bay when salinity ranged from 24.5-32.2 PSU and San Francisco Bay over in a larger range of salinities from 8.8- 32.1 ppt. A majority of 63.4% of their summer estuarine movements were non-directional and associated with the bottom. These individuals moved slowly with frequently changed direction and swim speed (Kelly et al. 2007). Considerable information should become available in the next year concerning coastal migrant and adult green sturgeon in the San Francisco Bay-Delta as a result of the Central Valley Fish Tagging Consortium's receiver arrays provides detailed temporal and spatial information about the movements of acoustically-tagged fish.

Green sturgeons exhibit a narrow and shallow depth distribution in the ocean. Green sturgeon typically swim in depths <100m over the continental shelf (Erickson and Hightower 2007). They move in shallower depths during the night than during the day, with occasional rapid-vertical ascents to the surface (Erickson and Hightower 2007). Green sturgeon migrate northward into Canadian waters during the fall, moving faster with a maximum rate of >45km day^{-1} during the spring (Lindley et al. 2008). There is an over-wintering aggregation site north of Vancouver Island and south of Cape Spencer, AK. Beamesderfer et al. (2007) modeled green sturgeon annual ocean survival to be 87% with natural mortality rate of 8%, and harvest mortality rate of 5%, and recent analyses (Lindley et al. 2008) of acoustically tagged recaptures in the ocean indicate survival is 83%, which is close to the proposed theoretical estimate.

Little is known about the prey of subadult and adult green sturgeon. They are presumed to be similar to other anadromous sturgeons and be secondary consumers and opportunistic predators of macrocrustaceans and bivalves in bay, subtidal, and intertidal habitats. Radtke (1966) identified *Corophium* sp. (amphipods) and *Neomysis* sp. (Opossum shrimp) in green sturgeon stomachs from the Delta. Stomaches of green sturgeon in San Pablo Bay contained the greatest variety of food items including *Corophium* sp., *Photis californica* (amphipod), *Cragon franciscorum* (Bay shrimp), *Macoma* sp. (clam), *Synidotea laticauda* (isopod), and unidentified crab and fish (Ganssle 1966). The stomachs of green sturgeon in Suisun Bay included *Corophium* sp., *C. franciscorum*, *Neomysis* sp., and annelid worms (Ganssle 1966). Shallow pits in intertidal areas are indicative of digging and predation by green sturgeon on burrowing shrimp such as *Neotrypaea* sp and *Upogebia pugettensis* in Willapa Bay, WA (Dumbauld et al. 2008). In Willapa Bay, WA, the coastal migrant and adult green sturgeon seemed to forage on macrocrustaceans (*Neotrypaea* sp., *U. pugettensis*, and *Crangon* sp.), bivalves, and benthic fishes.

Reproductively mature green sturgeons migrate into rivers prepared to spawn. Female green sturgeon presumably hold their eggs in an advanced stage of ovarian maturation until optimal water temperatures and the presence of males stimulate spawning. There have not been any observations of atresia in any riverine-captured fish on the Klamath or Rogue rivers (Van Eenennaam et al. 2006, Webb and Erickson 2007), suggesting cool water temperatures below 15° C limits egg degeneration and reabsorption through their spawning migration in these coastal rivers. Similar conditions are presumably optimal in the Sacramento River and tributaries for green sturgeon spawning migration. On the Rogue River, 95% of the females and 88% of the males appeared to be reproductively active or had recently spawned during the period of April to July (Webb and Erickson 2007). In this study, vitellogenic females and pre-meiotic males, both non-reproductive adult developmental stages, were observed in freshwater during the spring (Webb and Erickson 2007). Female and male green sturgeon captured during the fall in the Rogue River showed signs of gonadal tissue repair with 29% and 44% pre-meiotic, respectively, and this indicated they had already initiated their next gametogenic cycle (Webb and Erickson 2007).

F. Adult spawning migration, spawning, and post-spawning adults (Figure. 11)

Adult green sturgeon are presumed to migrate directly to spawning areas, though they may aggregate temporarily in the upper Delta during the spring or summer in an effort to migrate during the same period upstream to spawning areas or convene with outmigrating post-spawners. These staging behaviors have been observed in anadromous lake sturgeon on the St. Lawrence River (Hatin et al. 2002), and movement data on green sturgeon may demonstrate synchrony in spawning migration or outmigration. Green sturgeon carrying individually coded ultrasonic beacons entered the Golden Gate as early as February and as late as May and moved up the river to spawn (Heublein et al. in press). The tagged fish moved upstream rapidly to spawning areas. On the Sacramento River, adult green sturgeon were detected at Knights Landing in March and April, slightly earlier than spawning fishes in Northern DPS rivers. At the height of green sturgeon migration, which is typically reached during the period of early May 1 and late July, green sturgeon are most frequently found aggregating in isolated spots between Glenn-Colusa Irrigation District's site (GCID, Rkm331) upstream to Cow Creek at Rkm 451. Adult green sturgeon were present during late spring from Patterson riffle at Rkm 374 to immediately below the Red Bluff Diversion Dam at Rkm 391 frequently since 1981 (Brown (2007). Adult fish carrying ultrasonic beacons started their up-migration later than March, their upstream movement being impeded by the Red Bluff Diversion Dam (Heublein et al. in press). The apparent propensity for subadult and adult green sturgeon to aggregate in isolated freshwater habitats (S. Lindley, NOAA-Fisheries, Pers. Comm.; R. Corwin, Pers. Comm.) is similar to behavior observed in a resident population of lake sturgeon (Borkholder et al. 2002). While this behavior facilitates spawning, it is unclear for how long green sturgeon may aggregate and the reasons for this behavior later in the summer and fall seasons.

Very little information is known about adult green sturgeon habitats in the Sacramento River. Our understanding for green sturgeon riverine habitats is primarily based on the preferences of other sturgeon species and observations of bank substrate. Green sturgeon likely evolved a reproductive strategy to spawn in rapidly-flowing small rivers with their spawning grounds situated quite close to the river mouth (Artyukhin and Andronov 1990). Adult green sturgeon held in habitats greater than five meters depth in reaches characterized by small elevation gradients or off-channel coves of the rivers north of the Sacramento River (Benson et al. 2007, Erickson et al. 2002). Habitats like this are common on the Sacramento River, though it is unclear what physical or biological properties in deep pools favor green sturgeon occupancy.

Green sturgeon spawn in fast moving, turbulent waters in river reaches characterized by steep discontinuities in the channel slope and coarse cobble (Moyle 2002). These reaches often exist within canyons in the Klamath and Rogue rivers or reaches containing volcanic substrates in the Sacramento River. These habitats were situated primarily above Keswick Dam (Rkm 483), but now exist between Battle Creek and Red Bluff Diversion Dam such as at China Rapids and Iron Canyon. Green sturgeon eggs are highly adhesive (Van Eenennaam et al. 2008), indicating that their adhesiveness limits their movement downstream from spawning areas. Although spawning habitats may exist as far downstream as Glenn Colusa Irrigation District's diversion site, adults may need to swim farther up the river to ensure survival of eggs and larvae in suitable downstream reaches It is possible the temperature in the downstream reach may constrain the *realized* area available as larval nursery and juvenile foraging.

Once adult green sturgeons have spawned they appear to reside in rivers for up to six months until autumn or winter. This type of behavior has been observed in all spawning populations. On the Sacramento River, the area around Glenn-Colusa Irrigation District's diversion at 331 Rkm appears to be frequently occupied by green sturgeon as early as mid-June until early December (Heublein 2006), although sampling has not focused earlier than mid-June. On the Rogue River, green sturgeon restrict their movements to deep water, >5m in reaches separated by abrupt elevation changes or off-channel coves where the flows are slow (Erickson et al. 2002). Green sturgeon in the Klamath River were observed to spend the summer in a single location ranging from 44 to 199 days, although one individual was detected in multiple holding pools, staying for a minimum of one month at each pool (Benson et al. 2007). In the Klamath River, features such as rapids, outcrops of bedrock, and large boulders in the middle of the channel were frequently found in holding pools. Adult green sturgeon resided in freshwater over the summer, though a limited number of adult green sturgeon left in the late spring following spawning, although this may have been a response to tagging and handling stress (Benson et al. 2007). Green sturgeon used cues like increased flows and temperatures decreases below 10ºC associated with rainstorms to initiate their outmigration. On the Klamath River, green sturgeon outmigrated between 6.6-49.3 km $day^{-1}$and exited as late as December (Benson et al. 2007). In the lower Rogue River, the average swimming speed for two individuals ranged from 3.6-11.2 km day^{-1} (Erickson and Webb 2007)

IV. Stressor by stage and habitat (Table 4 and 5)

Green sturgeons are long lived, and thus face environmental and anthropocentric stressors that may affect the probability that they reach reproductive maturity. Males are observed to reproduce as early as 14 years old, while females grow older prior to maturing as early as 16 years old (Van Eenennaam et al. 2005). Both males and females occupy all types of aquatic environments- freshwater, estuarine, and marine. Numerous environmental factors potentially limit green sturgeon survival during the earliest stages of their life cycle while in freshwater. This period is called the "critical age" in fishes due to its relevance in survival and recruitment of individuals into the adult population (Hardy and Litvak 2004). Recruitment failure of the earliest life history stages may be a significant bottleneck for other North American acipenserids such as Pallid sturgeon and the white sturgeon in Upper Columbia and Kootenai rivers, the populations of which have numerous reproductive adults, but few recently surviving wild juveniles (Duke et al. 1999, Hildebrand et al. 1999, Korman and Walters 2001) .

There are many potential limiting factors during this early life period. They are the following: 1) warm water temperatures, 2) insufficient flows, 3) decreased dissolved oxygen, 4) lack of rearing habitat, and 5) increased predation. Water is released from Shasta Dam to maintain daily temperatures below 18º C downstream to a temperature compliance point, which in 2007 was maintained at Jellys Ferry and Balls Ferry to facilitate the incubation of eggs of spawning winter-run Chinook. This maintenance of cool water temperatures benefits green sturgeon spawning upstream of Red Bluff Diversion Dam. Temperature records from acoustic telemetry receivers along the mainstem have not been analyzed, but may provide data for assessing whether temperatures are limiting survival of embryos, larvae or juveniles downstream of RBDD. Once larvae grow into juveniles, their survival may be limited by lack of habitat, insufficient food, and possibly contaminants. Juveniles are fairly tolerant of variable temperature and dissolved oxygen, and are likely mobile enough to select favorable habitats (see Ecology sections). It is possible that juveniles can also be entrained in water diversions for farmland irrigation, although their benthic behavior likely limits this impact, and this is not well understood.

The members of the older age classes principally face anthropocentric threats to their survival in estuarine and marine environments. Once within the estuary, juveniles might accumulate pollutants such as methyl-mercury and pyrethroids, whose uptake is enhanced by the benthic feeding orientation of green sturgeon. Pyrethroids also may limit the availability of prey for young green sturgeon due to their effect of very low dosages on zooplankton and bottom-dwelling organisms. The size of the populations of subadults and adults have been potentially limited by human fisheries and barriers to spawning areas which may prevent them from racing the most optimal spawning habitats. Harvest can cause abrupt declines in green sturgeon adult abundance. Even an amount as small as 10% additional mortality over the green sturgeon's life-span can reduce population abundance by 50% and adult abundance by 90% (Beamesderfer et al. 2007). An additional simulated increase in mortality of 20% over natural mortality resulted in no green sturgeon surviving to adulthood. These forms of mortality could include human and nonhuman sources of direct mortality, and are not well quantified for the Southern DPS. Of greater concern, might be even much smaller additional mortality rates' influence on green sturgeon's reproductive potential. Additional rates of only 2-3% annual mortality over green sturgeon's life cycle reduced egg production to levels making sturgeon stocks extremely susceptible to overfishing (Beamesderfer et al. 2007).

A. Entrainment

Entrainment, or loss of life due to water pump, canal, or dam operations can be a problem for almost every life stage of green sturgeon- larvae, juveniles, subadults, and adults. While managers do not understand the impact of entrainment on green sturgeon in the Sacramento River, its effects may be predictable based on knowledge of behavior of the various life stages and past capture records from various water operation facilities. Larvae and juveniles may be trapped and killed at riverine and estuarine pumps located on the bottom when they are operated at night, since these life stages are benthic and are nocturnally active, presumably coming into shallower areas to feed. Juvenile green sturgeon have been entrained at the GCID diversion site and state and federal pumping facilities (CDFG 2002). Juvenile green sturgeon are entrained regularly at the Tracy and Banks Pumping Plants. While green sturgeon are vulnerable to impingement or entrainment at screened diversions when they are less than 30 mm in length, screening criteria for Delta smelt (0.1 fps) and juvenile salmon (0.33fps) were protective to juvenile green sturgeon (>30mm) in experiments (Swanson et al. 2004). It is possible subadult and adult green sturgeon are also affected by entrainment at the state and federal pumping facilities in the Delta because a small number of adult-sized fish were collected from Clifton Court Forebay in 1992-1993, and a 1.6 m green sturgeon was collected at the fish salvage facility in 2003 (Brent Bridges, BOR, Pers. Comm.). Adult green sturgeon are also killed as they are caught in the small space, through which water passes very rapidly, between the bottom and the moveable dam gates on Red Bluff Diversion Dam. This may significantly reduce the number of adults in the Sacramento River returning to the sea after spawning (Richard Corwin, Pers. Comm.). The overall impact of entrainment of fish populations is typically unknown (Moyle and Israel 2005), however there is enough descriptive information to predict where green sturgeon may be entrained.

B. Flow operations

Southern DPS green sturgeon likely spawned in the Sacramento, Feather, and San Joaquin rivers, judged upon the characteristics of the local habitats (Adams et al. 2007). Historic flows in these rivers during the upstream migration period occurring from March through July included increasing flows during winter rainstorms and spring melting of the snowpack. These flow increases enabled green sturgeon to migrate into the upper portions of these rivers with reaches characterized by high velocity flows and coarse river bed surfaces. Current flow management may inhibit the return of green sturgeon to the Sacramento River and Bay-Delta estuary by restricting seasonal flow necessary as cues for spawning and misdirection of juveniles during their outmigration. If similar to white sturgeon (Kohlhorst et al. 1991), seasonal flows during the April to June spawning migration for green sturgeon may also be correlated with juvenile green sturgeon recruitment. Flows also influence turbidity, dissolve oxygen, and temperature, and these all affect biological processed during green sturgeon's "critical period".

Although the effect of operations Delta Cross Channel are not known, they are open when juvenile and post-spawn green sturgeon are outmigrating through the lower Sacramento River headed to the Delta. This periodicity suggests that juvenile and post-spawn green sturgeon likely are redirected by these operations, which may delay migrations, expose fish to adverse conditions, or influence growth and survival.

C. Reservoir operations

In the upper Sacramento River, the flow volume and temperature of the river are dependent on water releases from Shasta and Keswick dams. Until the reservoirs are full in the late spring, the rate of water release is lower than naturally occurs, increasing only slightly during rains and rapid melting of the snows in the surrounding Trinity and Cascade mountains. The flows are generally 200 m^3/s in the spring, reaching 1,500 m^3/s during rainstorms (Brown 2007). Under these conditions, adult green sturgeon may move upstream and spawn in deep pools in the mainstem of the Sacramento River. Late in spring (usually on May 15), a series of gates are closed at the Red Bluff Diversion Dam, permitting water to form a temporary reservoir and then flow into irrigation canals leading to farmlands. Flows from May through September range from 280-425 m^3/s (Brown 2007). Large aggregations of green sturgeon have been observed in the pool below the diversion dam during May and June after the gates are closed (Richard Corwin, Pers. Comm.). It is unknown whether a high proportion of the late migrating green sturgeons that are forced to stay below the dam to spawn, move downstream to spawn, or possibly enter other large tributaries such as the Feather River. Based on preliminary results in 2008, it is possible that reservoir operations, which control temperature and flow, may actually lengthen the spawning period of green sturgeon in the area immediately downstream of RBDD (Israel et al., unpublished data).

Increased water flows presumably enhance spawning efficiency for green sturgeon. The flow of water on the Sacramento, Feather, and Yuba rivers is controlled by dams, and the flows can be predicted with high reliability. Thus, water managers can directly influence the successful production of larvae and juveniles. Outflow to the San Francisco Bay-Delta between April and July is significantly correlated with white sturgeon year class strength (Kohlhorst et al. 1991), and a similar relationship is presumed to exist with green sturgeon. Daily discharge at known green sturgeon spawning locations were similar to the estimated minimum necessary for strong age classes of white sturgeon on the Sacramento River (19,988 cfs, Neuman et al. 2007). On the Feather and Yuba rivers this volume of flow was not observed between 1996 and 2006. Additional study is necessary to understand how year class strength is correlated with flow rate. Increased water temperature decreases survival and increases mortality during gastrulation and yolk sac digestion. It is possible that river water temperature also influences spawning site selection although this has not been examined. Turbidity may increase the rate of fertilization of eggs (Van Eenennaam et al. 2008).

D. Habitat Loss

Managers do not know the historic spatial and temporal distribution of green sturgeon in the San Francisco Bay Delta. Assessments of historic habitat changes are based on our perception of what constitute optimal spawning, rearing, and foraging habitats. Dams on the Feather, Yuba, and San Joaquin rivers have changed the flow rate and period of temperatures favorable to green sturgeon embryo and larval survival, thus limiting recruitment on these systems. Dams and water conveyance structures (i.e., Themalito Outlet) have been built on these tributaries and their operation block passage by adult green sturgeon to preferred spawning habitats upstream of them. National Marine Fisheries Service (NMFS 2006) identified numerous potential adult migration barriers including RBDD, Sacramento Deep Water Ship Channel locks, Fremont Weir, Sutter Bypass, and the Delta Cross Channel Gates on the Sacramento River and Shanghai Bend and Sunset Pumps on the Feather River. In the Central Valley, approximately 4.6% of the total river kilometers have spawning habitat characteristics similar to where Northern DPS green sturgeon spawn (Neuman et al. 2007). Only 12% of this habitat is currently occupied. Of the 88% that is unoccupied (approx. 4000 kms) Neuman et al. (2007) found 44.2% is currently inaccessible due to dams.

Modification of the riverscape has resulted in loss of spawning habitat, rearing habitat, and increased barriers to migration. Larvae, juveniles, and adults life history stages are all benthic in orientation and all require deep habitats for dispersal, holding, and spawning. Successful fertilization and survival of embryos seems to require spawning habitats reflecting specific water quality and quantity parameters, which have been negatively impacted by construction of dams and channelization of the river. Riparian habitats provide allochthonous contributions to the river food web that indirectly support juvenile prey items. It is possible that modifications in temperature regime controlled by the Shasta Dam temperature control device may benefit green sturgeon spawning above Red Bluff Diversion Dam, but more research is necessary to understand the impacts of temperature on the distribution and success of green sturgeon spawning.

Channelization of the estuary has likely negative impacted the amount of subtidal and intertidal habitat available for green sturgeon foraging. These habitats have been lost along San Pablo and Suisun bays, where subadult and adult green sturgeon are commonly found. These estuarine habitats are likely important for growth during the juvenile, coastal migrant, and adults life stages. Invasive plant species in the estuary have likely impacted the quantity of shallow habitat available to coastal migrant and adult green sturgeon, and alterations of the food web due to invasive species have also likely shifted green sturgeon estuarine diet. Managers understand and the predictability of the impact of invasive species on green sturgeon is low and primarily based on observations of other species and ecology theory.

It is unknown if floodplains were a commonly used habitat by juvenile green sturgeon, though they may have served as migration corridors for adults. Since 1934, the Yolo bypass has been flooded and available for juvenile habitat before January in only 16 years (22% of the record). It is flooded into June once every fifty years, thus not typically available to larvae or riverine juveniles outmigrating to the estuary. Since 1934, the Yolo Bypass has been inundated after April in only 8 years (11% of the record), thus it is presumably a minor migration barrier for adults in a small number of years. It is possible subadult and adult fish use the drain, Cache Slough, and other perennially wetted portions of the bypass more frequently, but without inundation the Yolo bypass is not connected to the Sacramento River.

E. Water Quality

Water quality is likely a limiting factor during early life history stages of green sturgeon. Green sturgeons have a high rate of oxygen consumption and require high levels of dissolved oxygen to avoid stress (Gisbert et al. 2001, Lankford et al. 2003, Mayfield and Cech 2004). Eggs, embryos and larvae require higher levels of dissolved oxygen than juvenile green sturgeon, although growth does not seem to be controlled by dissolved oxygen. It is possible that low levels of dissolved oxygen results in chronic stress in young green sturgeon (Lankford et al. 2003), which forage in subtidal and intertidal Delta habitats and the Stockton Deep Water Ship Channel. However, there is high uncertainty and no knowledge about the presence of these conditions in particular habitats. Salinity can affect green sturgeon, although the predictability of this stressor is also limited. Peer-reviewed research has provided a clearer understanding of this stressor's effect and indicates the juvenile population of green sturgeon is physiologically heterogeneous. Thus, some juvenile green sturgeon are adapted to entering seawater earlier than others, who may be subjected to reduced foraging and survival in more saline environments (Allen and Cech 2007). Once in estuarine and seawater environments, seawater-tolerant green sturgeons seem to not be limited by the physical properties of the water due to their high mobility within these environments. Climate change will affect water quality and quantity, and may influence egg incubation, larval and juvenile growth rates, and spawning migration periodicity. While green sturgeon spawning persists in a reach of the Sacramento River with potentially cold waters regulated via the Shasta Dam temperature control device, the management utility of this tool with a changing climate is uncertain.

F. Toxics

Green sturgeons are long-lived fish which presumably forage annually in estuaries. Other anadromous sturgeon have been found to be as sensitive as salmonids to most contaminants, and green sturgeon should be presumed to be affected by water quality (Dwyer et al 2005). Estuarine food webs are often impacted by contaminants due to intensive modification of flows, sediment routing, and historic human influences. Manager's understanding of whether green sturgeons suffer from bioaccumulation of contaminants is limited. Green sturgeon do not spend as much time in estuaries as white sturgeon, but the effect of bioaccumulation of contaminants have been studies on this species in San Francisco Bay-Delta. Similar to white sturgeon, green sturgeons' growth, fecundity, and egg size are likely negatively affected by contaminants which persist for a long time in the environment like selenium and mercury (Linville 2006), Robert Kaufman, UCD, Pers. Comm.). Early life history stages may also be impacted, and Linville (2006) observed larvae to have increase skeletal deformities and mortality associated with maternal effects of selenium exposure. Increasing uptake of L-selenomethionine in juvenile green sturgeon results in an increase in mortality in fish fed 80mg Se/kg after only two weeks. Smaller quantities of 20mg/kg decreases feeding efficiency, and >20mg/kg reduced growth rates after four weeks (Lee et al. 2008a).

Methylmercury in sediments was highest in the Central Bay between 2002 and 2006, though shallower parts of San Pablo Bay and Suisun Bay also contained levels greater than 0.2 ppb (SFEI 2007). The amount methylmercury resulting in the death of juvenile green sturgeon lies between 20 to 40mg/kg, with greater consumption increasing mortality significantly (Lee et al. 2008b). Pollutants like endrocrine disruptors and pyrethroids, may also have effects on juvenile green sturgeon. Intersexual changes characterized by the formation of ovaries in males have been observed in shovelnose sturgeon and have been potentially linked to endocrine-disrupting organochlorine chemicals (Harshbarger et al. 2000). If green sturgeons are similar to other sturgeon, it would seem likely that pyrethroids accumulated in the tissues of members of the benthos even at extremely low level may affect ecological fitness by reducing growth, increasing disease, and producing abnormal swimming (Inge Werner, UC Davis, Pers. Comm.). This may impact juvenile green sturgeon more so than subadults or adults, due to their relative size. While multiple toxicants persist in the San Francisco Bay-Delta, the near- and long-term independent and synergistic effects of these chemicals on green sturgeon are unknown.

G. Invasives

Colonization of invasive species has negatively impacted the native Bay-Delta fish community. These species have likely impacted green sturgeon through changes in the food web by either increasing availability of new benthic species to their possible food resources or reducing native food resources. It is unknown whether these invasions by exotic bivalves, shrimp, and amphipods have led to dietary dilution, if they are inedible, or increased foraging opportunities for the generalist green sturgeon.

H. Population

Green sturgeons are long lived, and thus the cumulative effects of the stressors described above may have a major influence on the probability of them reaching reproductive maturity. Males may reproduce as early as 14 years old, while females grow older prior to maturing as early as 16 years old (Van Eenennaam et al. 2005). While younger age classes may be missing from the population's demography, it is possible that this lack of recruits is not observable until subadults are observed as bycatch in white sturgeon sports and commercial fisheries. Green sturgeon have traditionally been harvested as bycatch in commercial fisheries. The states of Washington, Oregon, and California eliminated legal sportsfishing and commercial bycatch of green sturgeon between 2006 and 2008. While uncommon, green sturgeon are still captured in Pacific Northwest and Sacramento River sports fisheries. On the Sacramento River, sturgeon fishing occurs farther upstream than white sturgeons typically migrate for spawning. In 2008, guides and private fishers were observed angling with rod and reel at "sturgeon hotspots" occupied principally by green sturgeon upstream of Tehama Bridge. These fishers viewed sturgeon fishing in these "hotspots" as catch and release fishing (J. Israel, Pers. Observation). The retention of green sturgeon is no longer allowed in California or the Pacific coast, except in tribal fisheries on the Klamath River (Adams et al. 2007). Chronic stress (i.e.: chasing, confinement, or depth reduction) has been observed to influence the bioenergetics of green sturgeon, though it did not influence their swimming performance (Lankford et al. 2005). Thus, fisher handling of green sturgeon is likely to have a minimal effect on survival. Poaching for sturgeon seems to be a threat in the Sacramento River, and green sturgeon may be illegally harvested in these operations. Manager's understanding for the effect of fishing-associated mortality on green sturgeon is low and the predictability of this stressor is little.

There is no hatchery for green sturgeon. Van Eenennaam et al. (2008) details protocols for spawning green sturgeon for use in conservation aquaculture. These protocols combined with a Hatchery and Genetic Management Plan for monitoring artificial propagation and its influence on the natural population should be formalized between regulatory and involved agencies and organizations prior to release of propagated fishes into the wild.

I. Other

Disease: It is unknown whether disease is a stressor in green sturgeon. Ongoing research in Lake Sturgeon is examining whether egg and larval densities influence disease transmission. No studies have evaluated disease transmission, the types of diseases potentially affecting green sturgeon, or their impact on green sturgeon population viability. NMFS (2006) stated there was not enough information to determine if disease played a role in the decline of Southern DPS green sturgeon.

V. Future Research

One conclusion of the NMFS Biological Review Team assessing the status of green sturgeon was that "it is essential that immediate efforts be undertaken to implement population monitoring for this [Southern] DPS using methods that directly assess population status" (NMFS 2003). Thus, these suggestions aim to focus on life history stages and processes critical to persistence of the species, which in green sturgeon are principally earlier in the life history. Although laboratory studies have yielded much information on the physiological needs of the species, field studies have yet to be completed applying this information to identifying adult spawning, larval survival, juvenile rearing, and juvenile smoltification. Information is necessary about the life history diversity, abundance, population growth rate, and riverscape structure (periodicity) of Sacramento River green sturgeon. Outside of the Sacramento River and San Francisco Bay-Delta, this same type of information is necessary for other spawning populations on the Klamath and Rogue rivers.

Developing flow and temperature recommendations for the middle Sacramento River during the spawning migration, spawning, and downstream larval transport stages of green sturgeon's life history are necessary for ensuring recruitment of green sturgeon in the long term. Water temperature data below Red Bluff Diversion Dam to Hamilton City should be collected with additional CDEC temperature stations installed to evaluate temperatures during April to October when eggs, larvae, juveniles, and adults are in this reach.

Parallel genetic studies and/or sonar (i.e. DIDSON) studies should be focused on estimating abundance of green sturgeon spawners in the Sacramento River. This will provide important information for determining the abundance of adult green sturgeon annually in the Sacramento River. These efforts should be advanced collaboratively and in a modeling framework so long-term data can be informative enough to improve estimates of green sturgeon abundance in the Sacramento River and Bay-Delta.

Managers should develop research and monitoring to estimate the riverine larval and juvenile populations for a period of time reflecting the potential variation in physical and biological processes influencing recruitment. These results will give managers an idea for the effect of management on critical habitats, influence of adult demography on recruitment dynamics, and the actual production of green sturgeon in younger cohorts. Estimates derived from these types of studies may be a good indication for spawning and abundance, which are not negatively influenced by the impact of entrainment, operations, and harvest. If estimates of young riverine fish are known, then adaptive research evaluating the impacts of anthropocentric stressors on older life history stages will allow managers to assess the actual effects of these anthropocentric stressors. Currently, abundance derived from harvest or operational entrainment data does not allow managers to determine if these impacts are causing declines in abundance or just reflect the natural production of spawning adults.

The distribution of spawning adults as well as a characterization of their spawning habitat within the Sacramento River should be completed. This will provide insight into the density of spawning adults and influence spawning aggregation have to the juvenile population, the rates of egg and larval mortality, and the potential loss of this spawning habitat by flow and temperature modification in the system. In 2008, UCD, BOR, and FWS initiated tracking green sturgeon as they move within the upper mainstem and collected eggs at spawning sites. Additional funding is necessary to adequately monitor spawning movements and increased egg and larval collection sites along the Sacramento riverscape to evaluate green sturgeon habitat relationships.

Little is known about green sturgeon food selection and foraging behavior making the predictability of where preferred food is available low. As green sturgeon move into the estuary and marine environments, food resources are not well understood. If native food sources have declined due to invasive species occupying their habitat or pollutants reducing available food, finding sufficient food may be problematic for juvenile green sturgeon. There is a need to investigate further the effects of selenium and other contaminants on green sturgeon and to find ways to reduce sources. Recent evidence indicates adult white sturgeon may be accumulating selenium in concentrations detrimental to reproduction, presumably by consuming the introduced overbite clam (Linville 2006).

The California Department of Fish and Game should invigorate their tagging efforts for green sturgeon in the Bay-Delta as an annual survey. CDFG should consider using acoustic telemetry and continuing PIT tag marking studies to track migrations, determine fidelity to spawning areas, monitor survival of fish salvaged at the pumping plants, and to locate important feeding and spawning areas. These data can be integrated into a hydrodynamic model of the watershed and estuary to determine if changes in flow regime affect movements of green sturgeon between spawning and rearing areas.

The State Water Project and Central Valley Project pumping plants in the south Delta capture green sturgeon in all life history stages. However, not known is what proportion of captured fish die as a result of capture. Does loss of life increase due to an increase in predation on fish drawn towards the plants? Does the contact with the screens harm individuals? To avoid future construction of conveyance facilities (i.e., pumping stations) to become stressors, research is necessary to develop screening criteria for green sturgeon larvae, juveniles, and adults. Additionally, given the limited opportunity for capturing green sturgeon, better coordination between salvage facilities and researchers may provide fish for field-based research. Scientists at UC Davis are currently obtaining juvenile sturgeon for their telemetric studies from these pump salvage facilities.

Support should be provided for priority research guided by the Interagency Ecological Program Sturgeon Work Team. This conceptual model should indicate that much is already known about the basic biology of green sturgeon from laboratory studies and can serve as the basis for developing hypotheses for testing in field studies. The next research step should be to discern the importance of this biology on population viability within the watershed. A systematically applied research program attempting to study the critical periods and habitats of green sturgeon in riverine and estuarine environments will provide managers with information on the actual utilization, status, and abundance of different life history stages of green sturgeon in the Sacramento River. Once these field observations are completed, our larger and more comprehensive understanding for the basic ecology of the species will permit the development of a population viability model, which could prioritize the above-mentioned risks to the population and guide management decisions.

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VII. Tables

Table 1. Green sturgeon life stage by biological measures. The abbreviation UNK is used where preferences are unknown.

	Habitat (*life stage*)	**Periodicity**	**Age (dph)**	**Weight (g)**	**Tail Length (cm)**	**Temperature (optimal) °C**	**Salinity range**	**Oxygen range**	**Turbidity range**	**Typical stage survival & fecundity**
1	**Upper/Middle Rivers** *Egg/embryo/ larvae*	April-July	< 10 dph[1]	<~0.1[1]	<1.3[1]	11-23 (<17)[2]	freshwater	>60% air saturation[3]	UKN	0.00< s < 0.28 (experimental[4])
2	**Upper/Middle Rivers** *Endogenously feeding larvae*	April - October	8-15 dph[1]	<~0.1[1]	1.3- 20[1]	11-23 (<17)[2]	freshwater	>60% air saturation[3]	UKN	s= UKN
3	**Middle/Lower rivers** *Young-of-year Juveniles*	~August - ~March	16-99 dph	~0.1-10[5]	20-60[5]	<27 (15-19)[5]	freshwater	UNK	UKN	s= UKN
4	**Delta/ Bay** *Juveniles*	all year	>100dph- 1.5 years	UKN	60-90[5]	<27 (15-19)[5]	freshwater-seawater	UNK	UKN	s= UKN
5	**Ocean/Delta/Bay** *Coastal Migrants*	all year	1.5- 13 years	UKN	90-152	UNK	freshwater-seawater	UNK	UKN	s~ 0.82[6]
6	**Delta/Bay** *Spawning Adult*	February- July	14 years - max. age[7]	19-73 kg[7]	152-243[7]	UNK	freshwater-seawater	UNK	UKN	s= UKN
7	**River** *Spawning Adult*	March- July	14 years - max. age[7]	19-73 kg[7]	152-243[7]	UNK	freshwater	UNK	UKN	s= UKN, f = 59,000-242,000[7]
8	**River /Delta** *Post-spawn*	May- January	14 years - max. age[7]	19-73 kg[7]	152-243[7]	UNK	freshwater-seawater	UNK	UKN	s= UKN
9	**Ocean/Delta** *Mature Adult*	all year	15 years - max. age	19-73 kg[7]	152-243[7]	UNK	seawater	UNK	UKN	s~ 0.82[6]

1. Deng et al. 2002. 2. Van Eenennaam et al 2005. 3. Gisbert et al 2001. 4. Van Eenennaam et al 2001. 5. Allen et al. 2006a. 7. Lindley et al 2008. 8. Van Eenennaam et al 2006.

Table 2. Green sturgeon life stage periodicity.

Egg/Embryo/Larvae

Sighting location	Jan		Feb		Mar		April		May		Jun		Jul		Aug		Sep		Oct		Nov		Dec	
RBDD									■	■	■	■	■	■	■	■								
GCID									■	■	■	■	■	■	■	■	■	■	■	■				

Juvenile

Sighting location	Jan		Feb		Mar		April		May		Jun		Jul		Aug		Sep		Oct		Nov		Dec	
River (GCID)	■	■			■	■											■	■	■	■	■	■		
Delta	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Suisun Bay	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
North Bay	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■								

Coastal migrant

Sighting location	Jan		Feb		Mar		April		May		Jun		Jul		Aug		Sep		Oct		Nov		Dec	
Coastal ocean	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Western Estuaries											■	■	■	■	■	■	■	■	■	■	■			

Spawning/Postspawning/Mature adult

Sighting location	Jan		Feb		Mar		April		May		Jun		Jul		Aug		Sep		Oct		Nov		Dec	
Sacramento River					■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
RBDD							■	■	■	■	■	■	■	■										
North Delta	■	■	■	■	■	■	■	■	■	■	■	■							■	■	■	■	■	■
South Delta	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
West Delta	■	■	■	■	■	■	■	■	■	■	■	■	■	■										
Suisun Bay	■	■	■	■	■	■	■	■	■	■	■	■	■	■										
North Bay	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■

Table 3. Green sturgeon larvae and juveniles observed at rotary screw traps at Glenn Colusa Irrigation District (GCID) and Red Bluff Diversion Dam (RBDD) between 1996 and 2008. Identification of enumerated fishes are assumed to be green sturgeon.

	GCID	RBDD
1996	337	410
1997	237	354
1998	0	302
1999	291	78
2000	35	-
2001	34	-
2002	9	35
2003	9	359
2004	6	264
2005	32	271
2006	6	193
2007	1	19
2008	0	0

Table 4. Green sturgeon life stage stressor matrix.

		A			B			C	D		
	Habitat (*life stage*)	**Entrainment: Small Ag.**	**Entrainment: Power Plant**	**Entrainment: SWP/CVP**	**Flow Operations: Delta Cross Channel**	**Flow Operations: S. Delta Operable Gates**	**Flow Operations: Barriers**	**Reservoir Operations: Altered seasonal flows**	**Habitat Loss: Prey Availability**	**Habitat Loss: Spawning**	**Habitat Loss: Rearing**
1 & 2	**Upper/Middle Rivers** *Egg/embryo/ larvae/ Endogenously feeding*	RBDD: direct mortality & salvage						Volume of flow influences tranport and dispersal			affects growth and survival
3	**Middle/Lower rivers** *Juveniles*	GCID: direct mortality & salvage			affects migration pathways			Volume of flow influences tranport and dispersal	affects survival and growth		affects growth
4	**Delta/Bay** *Juveniles*	direct mortality & salvage	direct mortality & salvage	direct mortality & salvage	affects migration pathways				affects survival and growth		
5	**Ocean/Delta/Bay** *Coastal Migrants*			salvage	affects migration pathways	affects migration pathways	affects migration pathways		affects survival and growth rate		
6	**Delta/Bay** *Spawning Adult*				affects migration pathways	affects migration pathways	affects migration pathways	affects spawning migration			
7	**River** *Spawning Adult*	RBDD: direct mortality						affects spawning habitat selection		affects spawning behavior and success	
8	**River/ Delta** *Post-spawn*	RBDD: direct mortality	direct mortality	direct mortality	affects migration pathways		affects migration pathways	affects post-spawning migration	affects growth rate		
9	**Ocean/Delta/Bay** *Mature Adult*				affects migration pathways		affects migration pathways		affects growth rate		

Table 4 continued. Green sturgeon life stage stressor matrix.

		D continued		**E**				**F**	
	Habitat (*life stage*)	**Habitat Loss: Migration**	**Habitat Loss: Foraging**	**W. Quality: Temperature**	**W. Quality: Diss. Oxy.**	**W. Quality: Turbidity**	**W. quality: Salinity Distribution**	**Toxics: Heavy Metals**	**Toxics: Pesticides**
1 & 2	**Upper/Middle Rivers** *Egg/embryo/ larvae/ Endogenously feeding*			affects fertilization, survival, and growth rates	affects survival, development, and growth rates	affects fertilization and predation rates			
3	**Middle/Lower rivers** *Juveniles*		affects survival and growth	affects survival and growth	affects survival and growth		affects survival and growth		affects survival and growth
4	**Delta/Bay** *Juveniles*	affects survival by altering movement	affects survival and growth	affects stress response	affects stress response	affects foraging	affects survival and growth		affects survival and growth
5	**Ocean/Delta/Bay** *Coastal Migrants*							affects growth	affects growth
6	**Delta/Bay** *Spawning Adult*							affects growth	affects growth
7	**River** *Spawning Adult*			affects spawning habitat selection	affects spawning habitat selection	affects spawning habitat selection		affects fecundity	
8	**River/ Delta** *Post-spawn*		affect post-spawn recovery	affects holding habitat selection	affects holding habitat selection				
9	**Ocean/Delta/Bay** *Mature Adult*			affects stress response	affects stress response			affects reproductive maturation	affects reproductive maturation

Table 4 continued. Green sturgeon life stage stressor matrix.

		G		H				I
	Habitat (*life stage*)	**Invasives: Competition**	**Invasives: Predation**	**Population: Allee effect**	**Population: Hybridization**	**Population: Harvest**	**Population: Disease**	**Other**
1 & 2	**Upper/Middle Rivers** *Egg/embryo/ larvae/ Endogenously feeding larvae*		affects survival		affects survival		affects survival	Dredging: direct mortality
3	**Middle/Lower rivers** *Juveniles*	affects growth	affects survival				affects survival	Dredging: direct mortality
4	**Delta/Bay** *Juveniles*	affects growth	affects survival					Dredging: direct mortality
5	**Ocean/Delta/Bay** *Coastal Migrants*					direct mortality		Boat strikes: direct mortality
6	**Delta/Bay** *Spawning Adult*					direct mortality		Boat strikes: direct mortality
7	**River** *Spawning Adult*			affects finding mates		direct mortality		Boat strikes: direct mortality
8	**River/ Delta** *Post-spawn*					direct mortality		Boat strikes: direct mortality
9	**Ocean/Delta/Bay** *Mature Adult*					direct mortality		Boat strikes: direct mortality

Table 5. Green sturgeon life stage stressor matrix with importance, understanding, and predictability scores.

		A			B		C	D		
	Habitat (*life stage*)	**Entrainment Small Ag.**	**Entrainment Power Plant**	**Entrainment SWP/CVP**	**Flow Ops: Delta Cross Channel**	**Flow Ops: Barriers**	**Reservoir Ops: Altered seasonal flows**	**Habitat Loss: Prey Availability**	**Habitat Loss: Spawning**	**Habitat Loss: Rearing**
1	**Upper/Middle Rivers** *Egg/Embryo/ Larvae/Feeding larvae*	I = 4 U = 2 P = 3					I = 3 U = 2 P = 3			I = 3 U = 1 P =
3	**Middle/Lower rivers** *Juveniles*	I = 2 U = 1 P = 2			I = 2 U = 1 P = 2		I = 2 U = 2 P = 3	I = 2 U = 1 P = 1		I = 2 U = 1 P = 2
4	**Delta /Bay** *Juveniles*	I = 2 U = 2 P = 2	I = 1 U = 1 P = 1	I = 2 U = 3 P = 3	I = 2 U = 1 P = 2			I = 2 U = 1 P = 1		I = 2 U = 1 P = 1
5	**Delta** *Coastal Migrants*			I = 2 U = 1 P = 1	I = 2 U = 1 P = 2			I = 2 U = 1 P = 1		
6	**Delta/Bay** *Spawning Adult*				I = 2 U = 1 P = 2		I = 3 U = 2 P = 2			
7	**River** *Spawning Adult*	I = 4 U = 2 P = 2					I = 3 U = 2 P = 3		I = 4 U = 3 P = 2	
8	**River/Delta** *Post-spawn*	I = 2 U = 2 P = 2	I = 1 U = 1 P = 1	I = 1 U = 1 P = 1	I = 2 U = 1 P = 2	I = 2 U = 1 P = 2	I = 2 U = 2 P = 3			
9	**Ocean/Delta/Bay** *Mature Adult*									

Table 5 continued. Green sturgeon life stage stressor matrix with importance, understanding, and predictability scores.

		D continued		E				F	
	Habitat (*life stage*)	**Habitat Loss: Migration**	**Habitat Loss: Foraging**	**W. Quality: Temperature**	**W. Quality: Diss. Oxy.**	**W. Quality: Turbidity**	**W. quality: Salinity Distribution**	**Toxics: Heavy Metals**	**Toxics: Pesticides**
1	**Upper/Middle Rivers** *Egg/Embryo/ Larvae/ Feeding larvae*			I = 3 U = 3 P = 3	I = 3 U = 3 P = 2	I = 3 U = 1 P = 1			
3	**Middle/Lower rivers** *Juveniles*		I = 2 U = 1 P = 2	I = 3 U = 3 P = 3	I = 2 U = 2 P = 2	I = 2 U = 1 P = 1	I = 3 U = 1 P = 2		I = 2 U = 2 P = 2
4	**Delta /Bay** *Juveniles*	I = 2 U = 1 P = 1	I = 2 U = 1 P = 1	I = 2 U = 2 P = 2	I = 2 U = 2 P = 2		I = 3 U = 1 P = 2	I = 2 U = 2 P = 2	I = 2 U = 2 P = 2
5	**Delta** *Coastal Migrants*							I = 2 U = 2 P = 2	I = 2 U = 2 P = 2
6	**Delta/Bay** *Spawning Adult*							I = 2 U = 1 P = 2	I = 2 U = 1 P = 2
7	**River** *Spawning Adult*			I = 3 U = 1 P = 3	I = 3 U = 1 P = 3	I = 2 U = 1 P = 1			
8	**River/Delta** *Post-spawn*		I = 2 U = 1 P = 1	I = 2 U = 1 P = 3	I = 2 U = 1 P = 3			I = 2 U = 1 P = 2	I = 2 U = 1 P = 2
9	**Ocean/Delta/Bay** *Mature Adult*			I = 2 U = 1 P = 1	I = 2 U = 1 P = 1			I = 2 U = 1 P = 2	I = 2 U = 1 P = 2

Table 5 continued. Green sturgeon life stage stressor matrix with importance, understanding, and predictability scores.

		G		H				I
	Habitat (*life stage*)	**Invasives: Competition**	**Invasives: Predation**	**Population: Allee effect**	**Population: Hybridization**	**Population: Harvest**	**Population: Disease**	**Other**
1	**Upper/Middle Rivers** *Egg/Embryo/ Larvae/ Feeding larvae*		I = 2 U = 1 P =1		I = 1 U = 1 P =1		I = 2 U = 1 P = 1	I = 2 U = 1 P = 1
3	**Middle/Lower rivers** *Juveniles*	I = 2 U = 1 P =1	I = 2 U = 1 P =1				I = 2 U = 1 P = 1	I = 2 U = 1 P = 1
4	**Delta /Bay** *Juveniles*	I = 2 U = 1 P =1	I = 2 U = 1 P =1					I = 2 U = 1 P = 1
5	**Delta** *Coastal Migrants*					I = 3 U = 2 P = 3		I = 2 U = 1 P = 1
6	**Delta/Bay** *Spawning Adult*					I = 2 U = 2 P = 3		I = 2 U = 1 P = 1
7	**River** *Spawning Adult*			I = 2 U = 1 P = 1		I = 3 U = 2 P = 3		I = 2 U = 1 P = 1
8	**River/Delta** *Post-spawn*					I = 2 U = 2 P = 3		I = 2 U = 1 P = 1
9	**Ocean/Delta/Bay** *Mature Adult*					I = 3 U =3 P = 3		I = 2 U = 1 P = 1

Explanation of importance, understanding and predictability.

4 = High importance: expected sustained major population level effect, e.g., the outcome addresses a key limiting factor, or contributes substantially to a species population's natural productivity, abundance, spatial distribution and/or diversity (both genetic and life history diversity) or has a landscape scale habitat effect, including habitat quality, spatial configuration and/or dynamics.
3 = Medium importance: expected sustained minor population effect or effect on large area or multiple patches of habitat
2 = Low importance: expected sustained effect limited to small fraction of population, addresses productivity and diversity in a minor way, or limited spatial or temporal habitat effects
1 = Minimal or no importance: Conceptual model indicates little or no effect

4 = High predictability: Understanding is high and nature of outcome is largely unconstrained by variability in ecosystem dynamics, other external factors, or is expected to confer benefits under conditions or times when model indicates greatest importance.
3 = Medium predictability: Understanding is high but nature of outcome is dependent on other highly variable ecosystem processes or uncertain external factors. OR Understanding is medium and nature of outcome is largely unconstrained by variability in ecosystem dynamics or other external factors
2 = Low predictability: Understanding is medium and nature of outcome is greatly dependent on highly variable ecosystem processes or other external factors OR Understanding is low and nature of outcome is largely unconstrained by variability in ecosystem dynamics or other external factors
1 = Little or no predictability: Understanding is lacking OR Understanding is low and nature of outcome is greatly dependent on highly variable ecosystem processes or other external factors

4 = High understanding: Understanding is based on peer-reviewed studies from within system and scientific reasoning supported by most experts within system.
3 = Medium understanding: Understanding based on peer-reviewed studies from outside the system and corroborated by non peer-reviewed studies within the system.
2 = Low understanding: Understanding based on non peer-reviewed research within system or elsewhere.
1 = Little or no understanding: Lack of understanding. Scientific basis unknown or not widely accepted

VIII. Figures

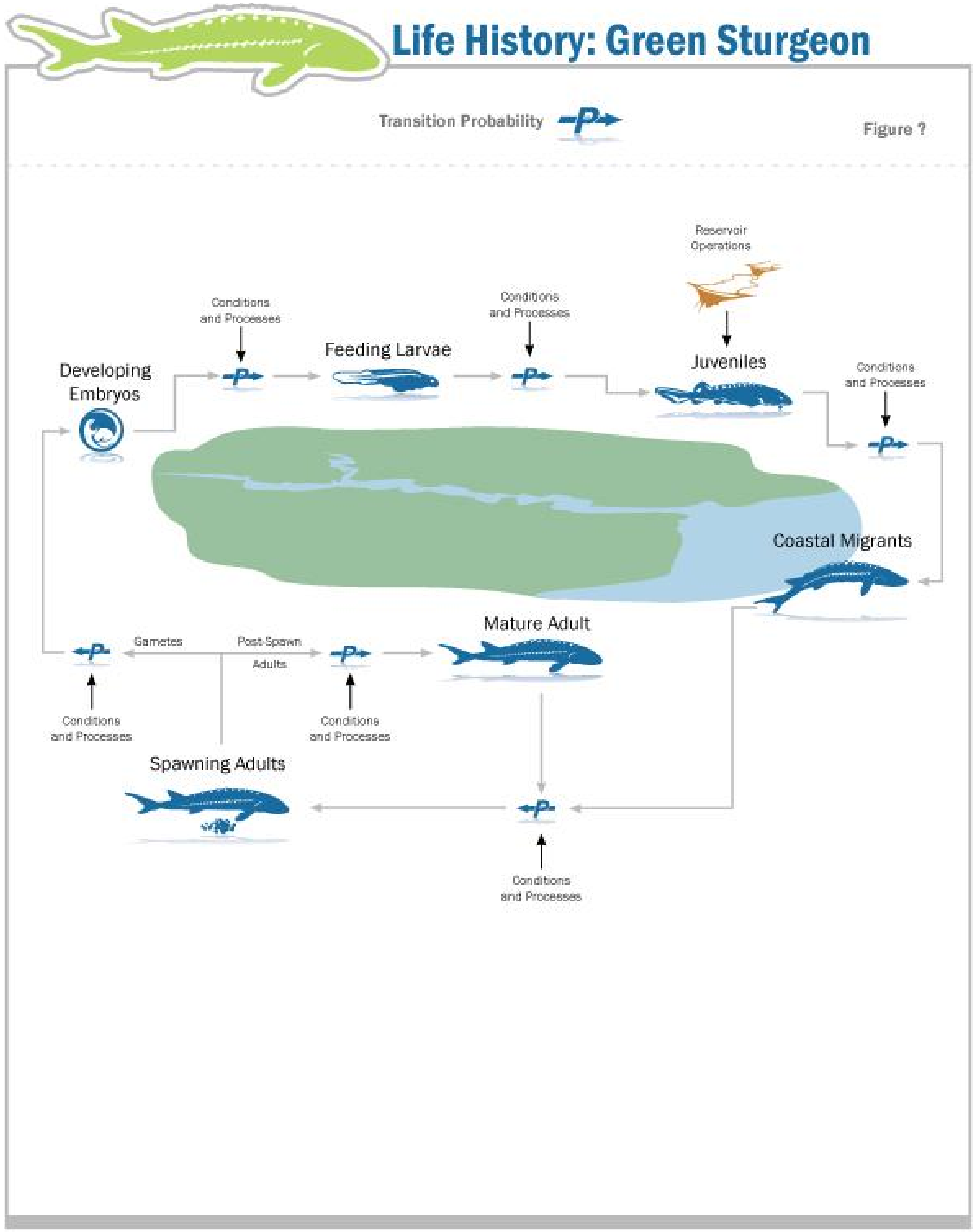

Figure 1. Conceptual model of *Acipenser medirostris* life history (modified from Wildhaber et al. 2007).

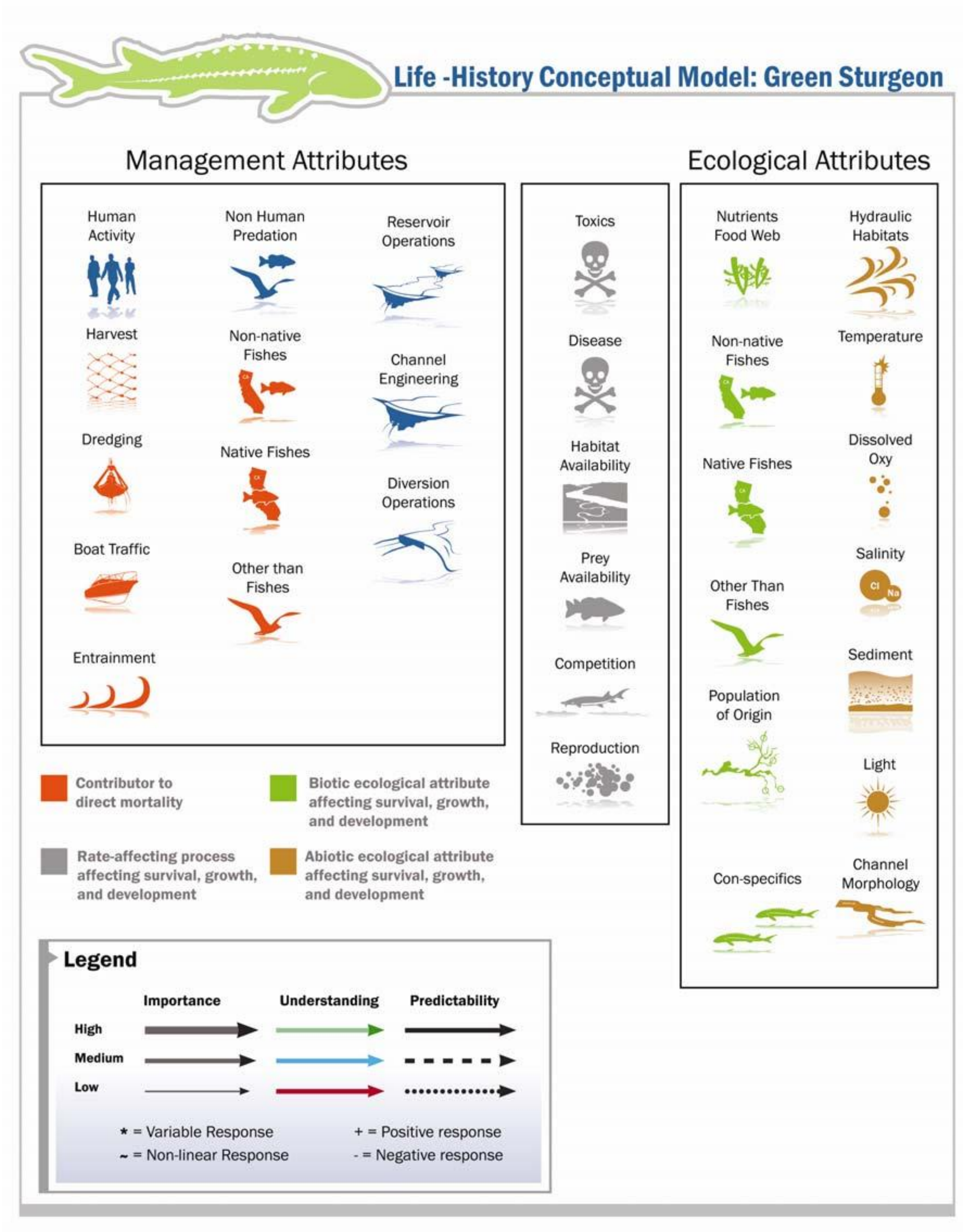

Figure 2. Symbols and labels used in submodels of the *Acipenser medirostris* conceptual model (modified from Wildhaber et al. 2007).

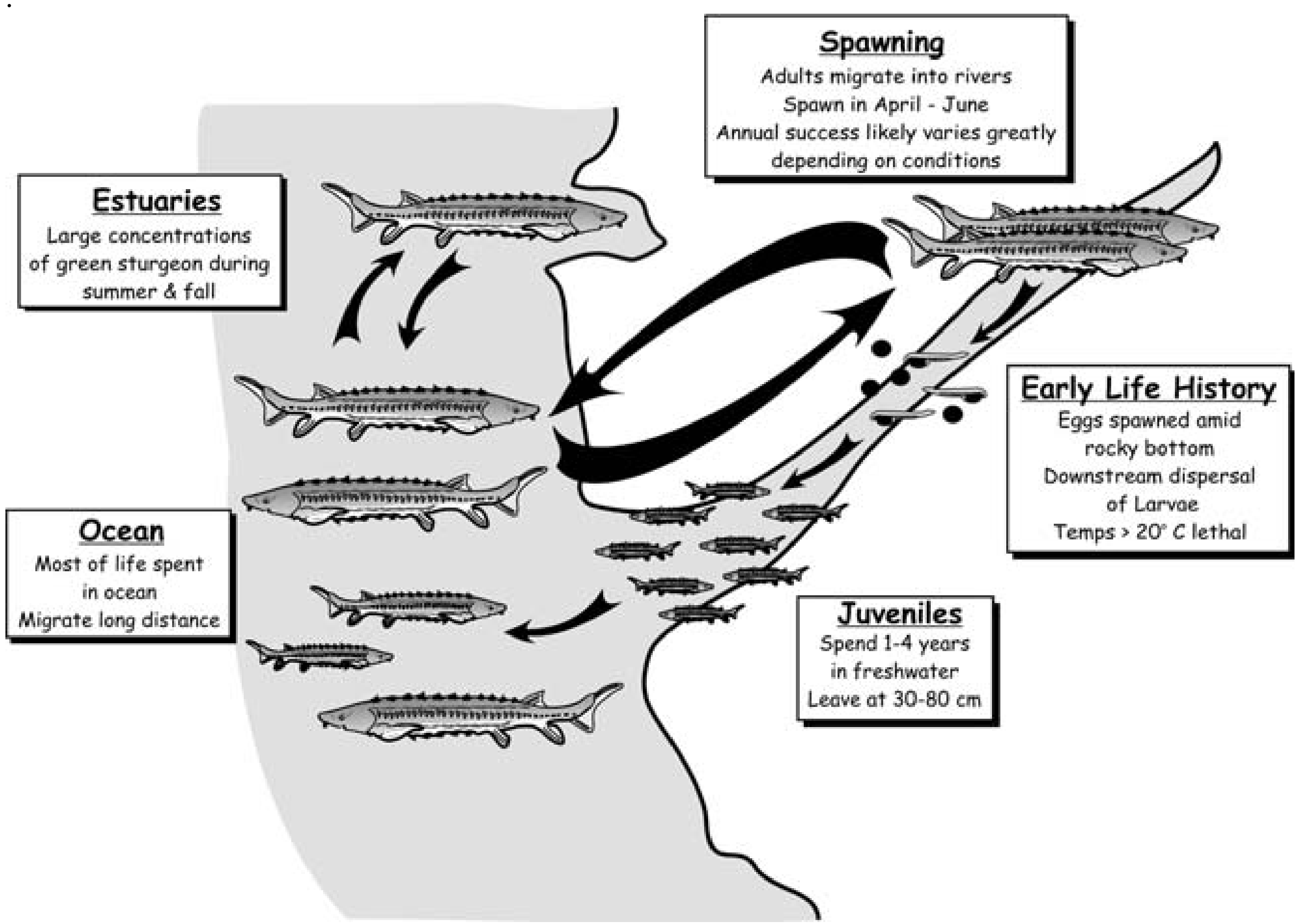

Figure 3. Green sturgeon life history biology diagram from Beamesderfer et al (2007)

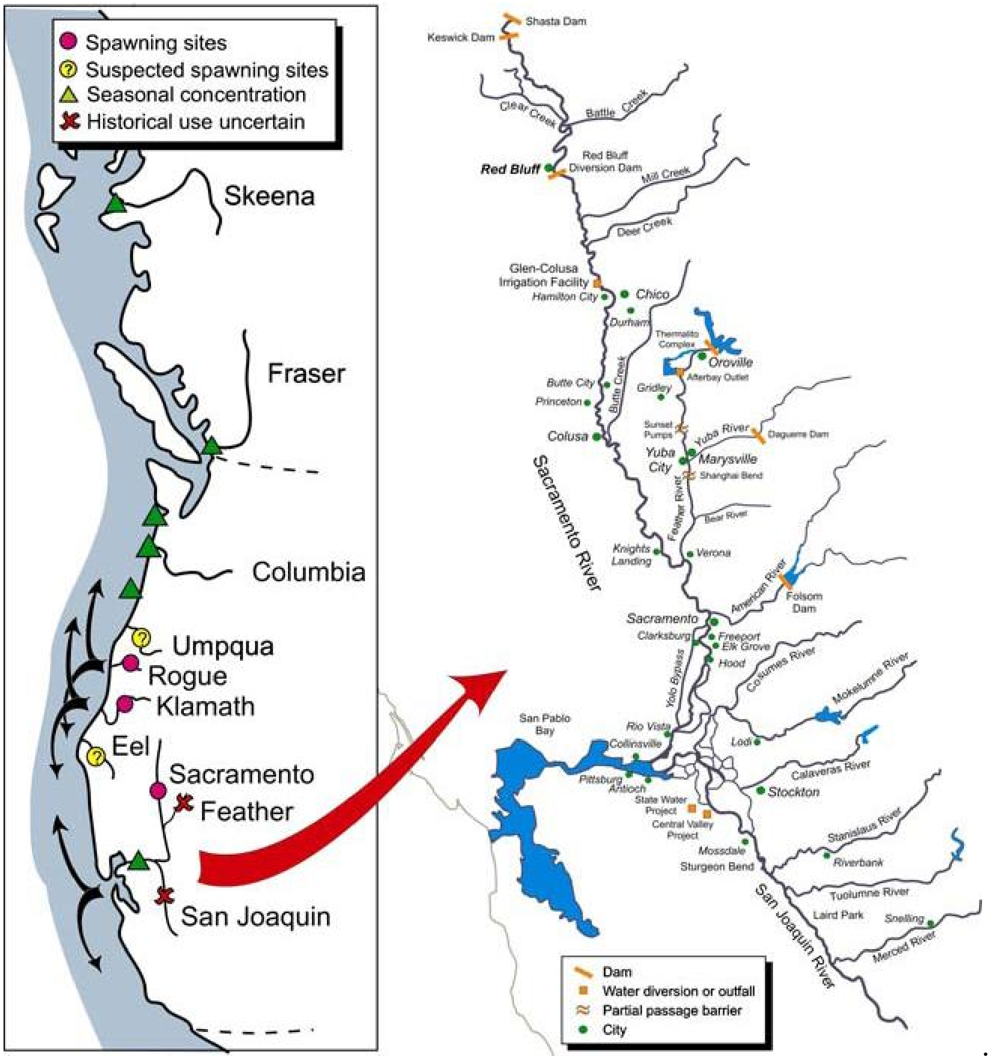

Figure 4. Green sturgeon habitats and distribution from Beamesderfer et al. (2007)

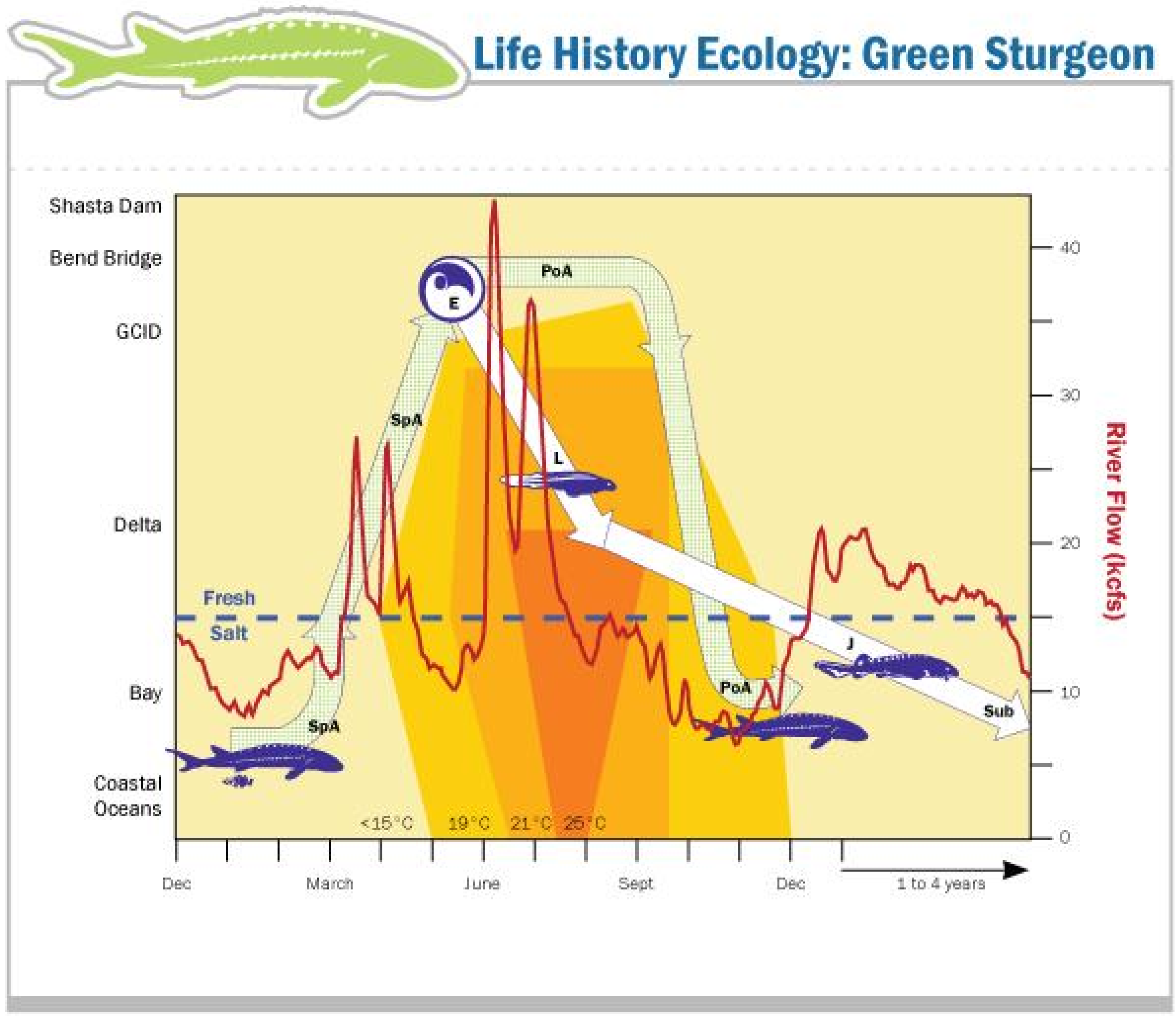

Figure 5. Life history ecology diagram. Spawning green sturgeon adults (SpA) enter the river in the spring to spawn and outmigrate as post-spawners (PoA). Eggs (E) are broadcast spawned and mature into larvae (L), enter the estuary at juveniles (J), then migrate into coastal ocean habitats as subadults (Sub). Black line represents 2006 daily average flow at Vernalis (waterdata.usgs.gov). Temperature data are 2006 data from Bend Bridge, GCID, Bethel Island, Port Chicago, and Martinez (cdec.water.gov).

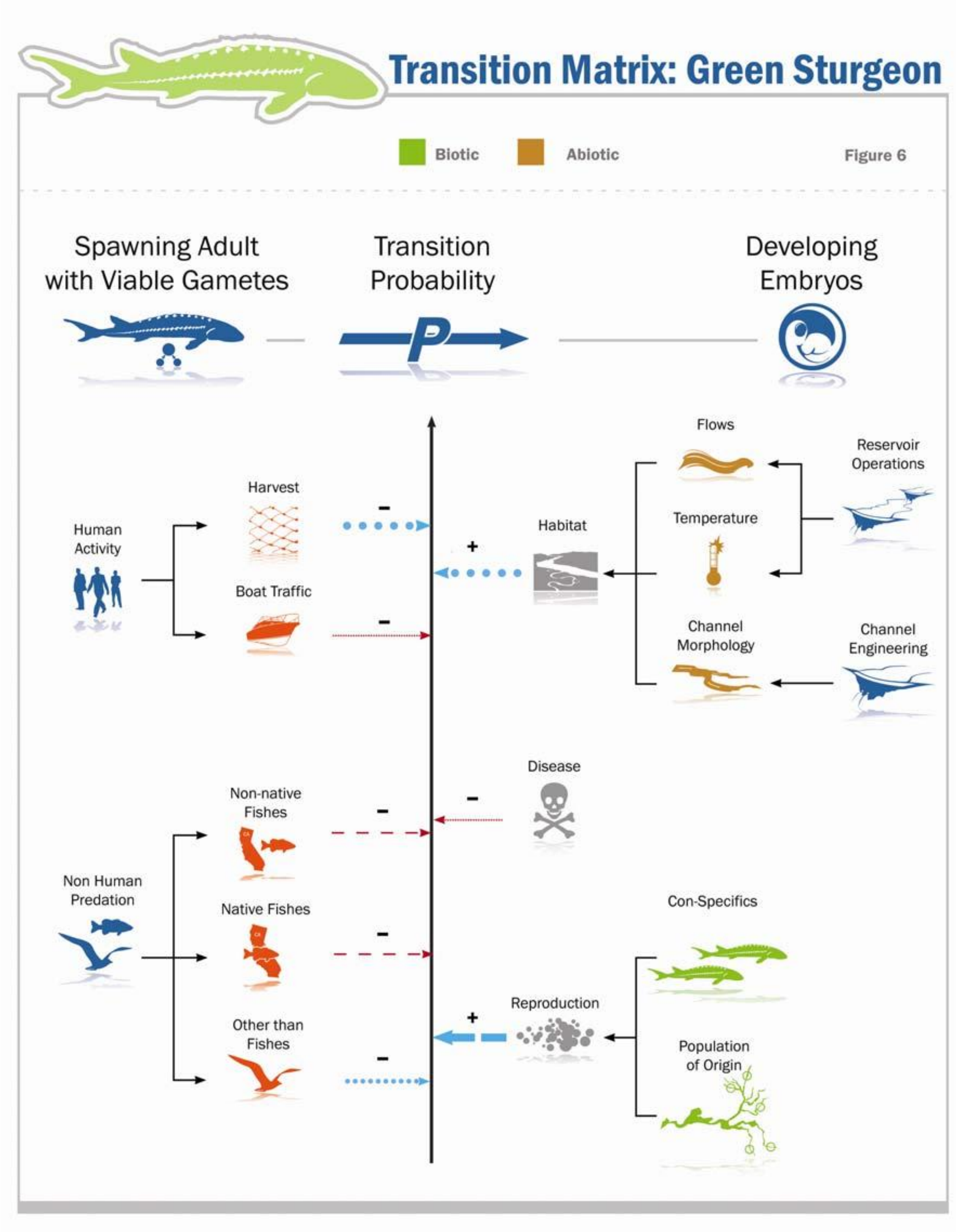

Figure 6. Submodel for the transition from spawning adult with viable gametes to developing embryo stage in the *Acipenser medirostris* life history conceptual model.

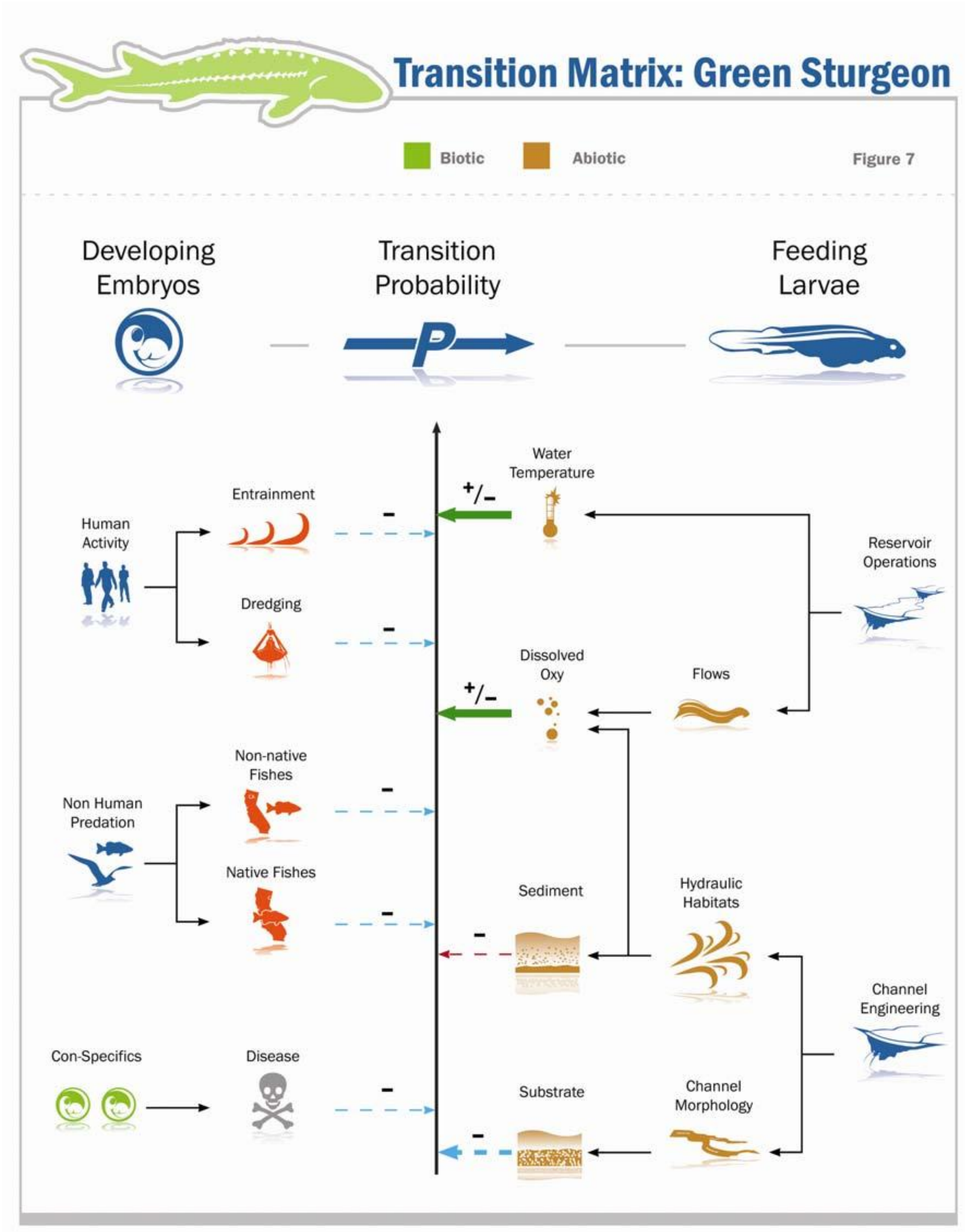

Figure 7. Submodel for the transition from developing embryo to larval stage of exogenous feeding in the *Acipenser medirostris* life history conceptual model.

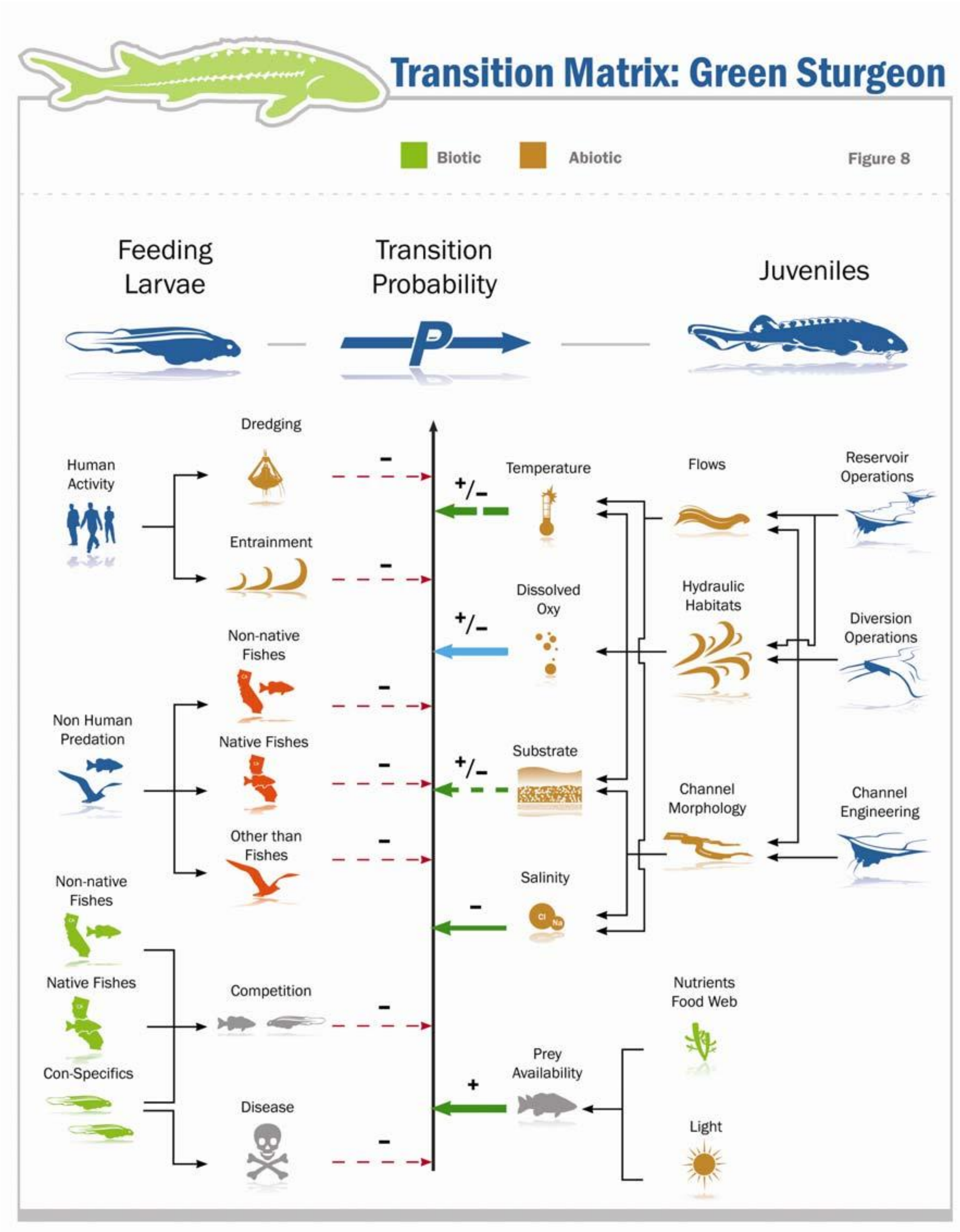

Figure 8. Submodel for the transition from larval stage of exogenous feeding to juvenile stage in the *Acipenser medirostris* life history conceptual model.

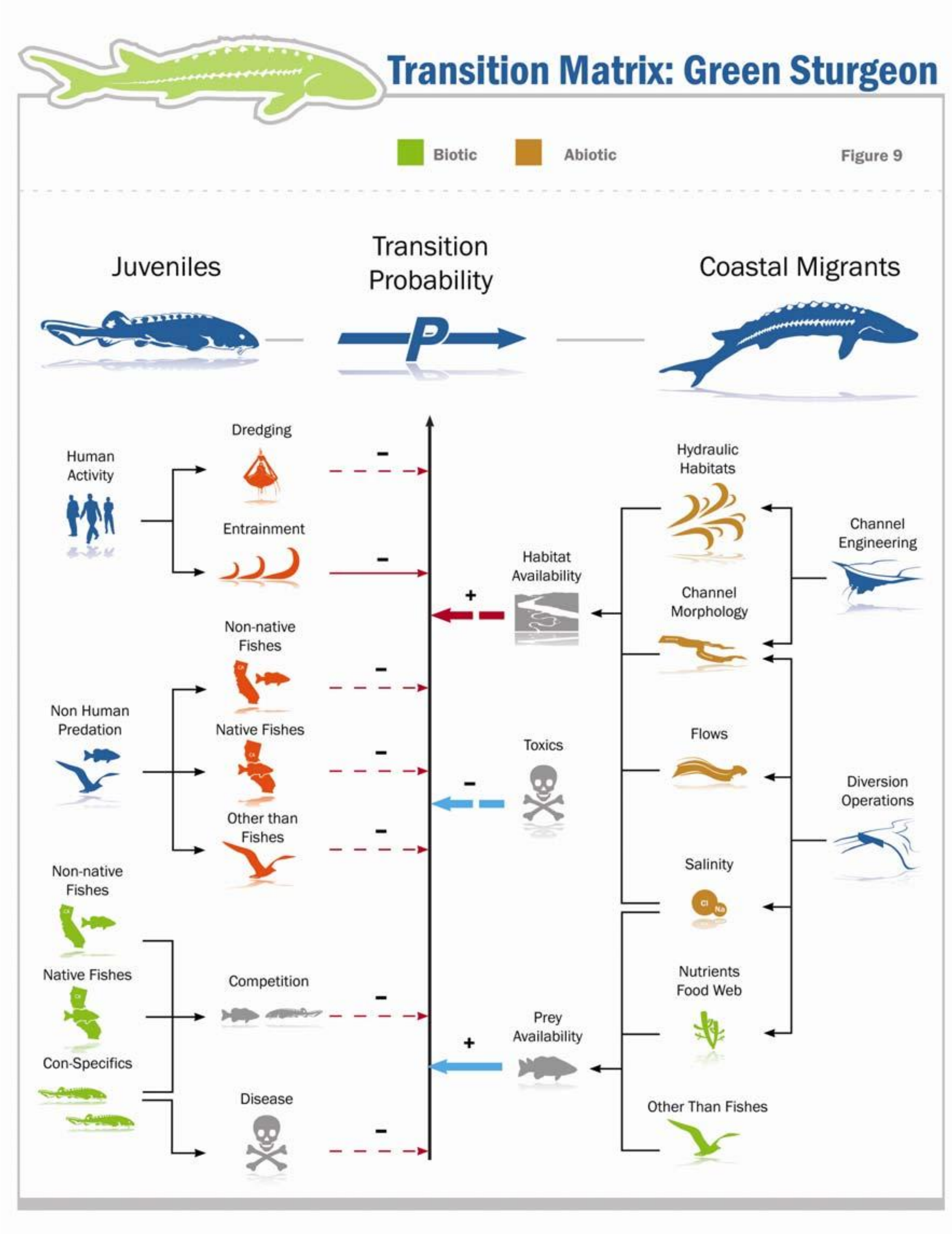

Figure 9. Submodel for the transition from juvenile stage to coastal migrant in the *Acipenser medirostris* life history conceptual model.

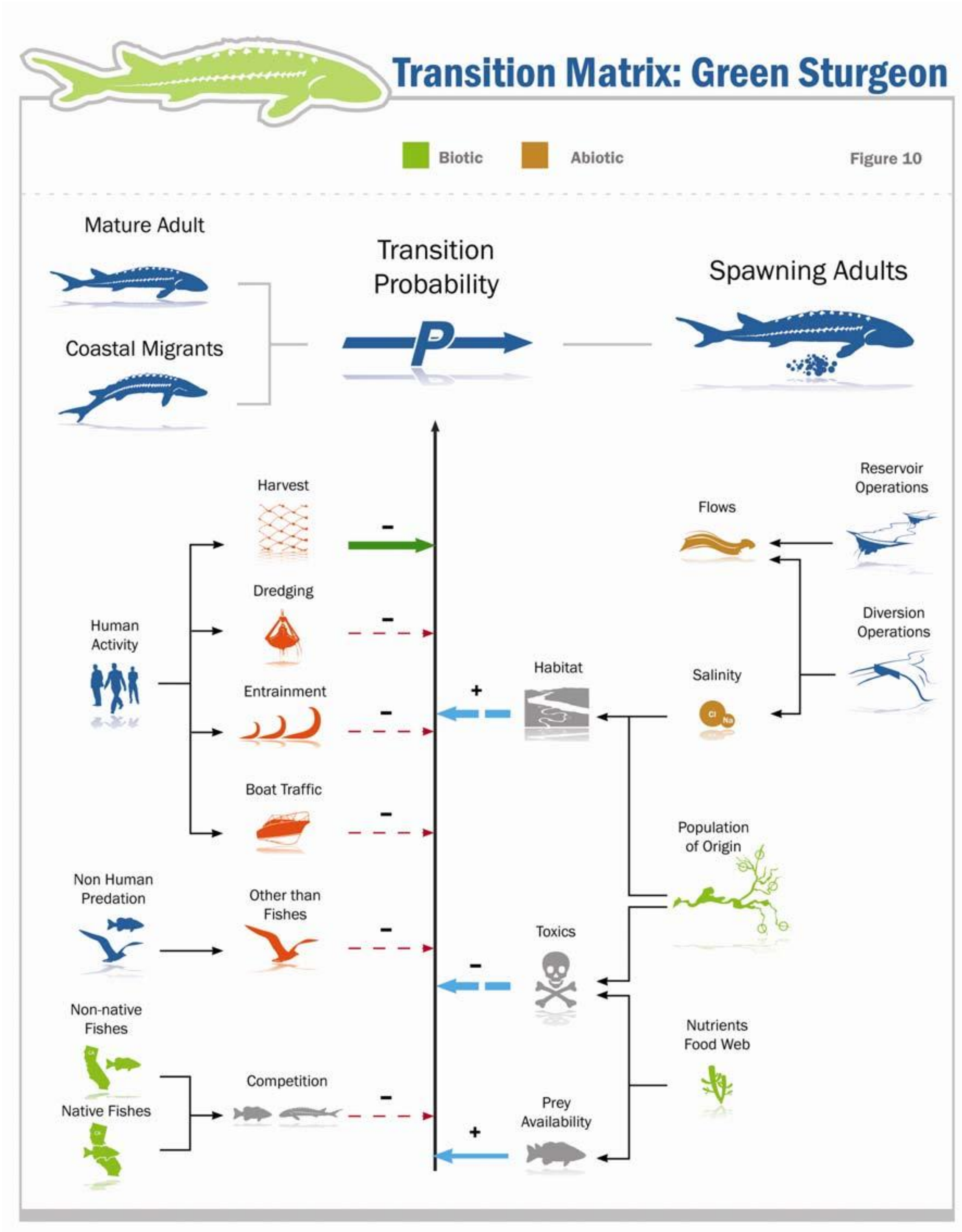

Figure 10. Submodel for the transition from coastal migrant to spawning adult with viable gametes in the *Acipenser medirostris* life history conceptual model.

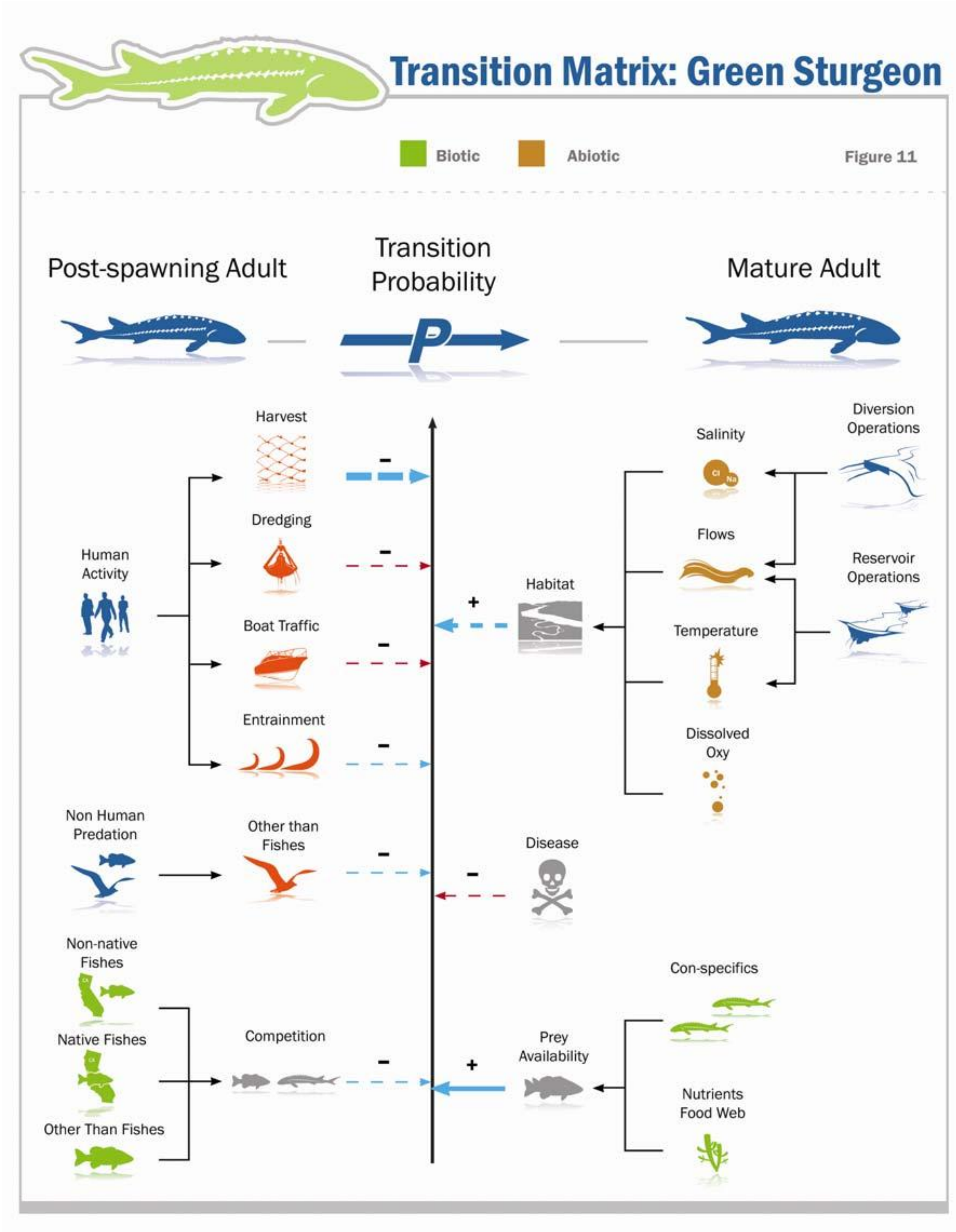

Figure 11. Submodel for the transition from spawning adult with viable gametes to Mature Adult stage in the *Acipenser medirostris* life history conceptual model.