Guidelines to Evaluate, Modify and Develop Estuarine Restoration Projects for Tidewater Goby Habitat

FINAL REPORT

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Executive Summary

The objective of this document is to provide hydrologic and biologic guidelines that will assist resource managers as they implement habitat restoration or enhancement activities for the federally listed (endangered) tidewater goby (*Eucyclogobius newberryi*). This document is being provided to the U.S. Fish and Wildlife Service (USFWS), other resource agencies, and local non-governmental organizations seeking to restore or enhance estuarine, lagoon and coastal freshwater habitats in Humboldt Bay and the north coastal California area. This document has general applicability for projects in other areas to the south, however local conditions need to be taken into consideration due to variability in habitat parameters throughout the range of the tidewater goby. With assistance from private restoration practitioners, resource agencies are seeking to restore wetland/estuarine habitats along the north coast of California, focusing on providing conditions that benefit native fish species listed under the Endangered Species Act. To date, restoration efforts have emphasized habitat improvement for native anadromous salmonids. Tidewater goby habitat requirements often overlap those of juvenile salmonids (e.g., brackish water marshes and other estuarine habitats). Many opportunities exist where an estuarine restoration project can benefit both species. However, the habitat requirements of the tidewater goby differ enough that restoration for salmonids, in some instances, may not be beneficial to tidewater goby populations.

This report documents how one might use these guidelines as follows:

- Evaluation of tidewater goby habitat requirements.
- Evaluation of modeling techniques to design restoration projects (including a review of available models and how to select models).
- Monitoring of restoration projects in tidally influenced areas or other areas where tidewater gobies occur, where tidal effects may be muted or lacking, for example in lagoons.
- Identification of specific restoration scenarios and future needs affecting the tidewater goby.

Habitat characteristics were evaluated for tidewater goby in general, and more specifically when available, for spawning, juvenile, and adult goby life stages, using the available literature. Reproduction/spawning typically occurs in slack, shallow waters in seasonally disconnected (from the ocean) or tidally muted lagoons, estuaries, and sloughs. Males dig burrows and guard eggs, peaking in early spring and late summer in some areas. Males in burrows and eggs, as well as larvae, are likely less tolerant of floods, breaching, or tidal exchange. Preferred reproduction/spawning water temperatures are 15–24°C (59–75°F) within a range of 2–27°C (36–81°F) as reported by the literature. Preferred salinities (ppt) for reproduction/spawning were identified as ≤ 15 within a range of 5–25. Preferred depths for tidewater goby reproduction/spawning were identified as 20–100 cm (8–39 in), however reported depth preferences are likely biased due to methods of sampling (e.g., beach seine). Substrate preferences appear to be sand, coarse sand, and sand/mud.

The preferred juvenile/adult habitat is also slack, shallow water in seasonally disconnected or tidally muted lagoons, estuaries, and sloughs. Flood refugia for juveniles/adults include "perched" habitats, off-channel sloughs, and pockets of still water. Juveniles and adults can be found year-round, although they are most abundant in summer/fall. Juvenile/adult life stages can tolerate flooding/breaching in late fall/winter. Substrate preference is for sand, mud, gravel, and silt, particularly associated with submerged vegetation that is likely used for cover. Juvenile/adult tidewater gobies were reported to prefer water temperatures of 12–24ºC (54–75°F) within a range of 6–25ºC (42–77°F). Salinities (ppt) preferred by juvenile/adults were reported to be ≤ 15 and within a range of 0–51. The literature indicates that preferred depths of juvenile and adult tidewater gobies range from 20–100 cm (8–39 in), based on sampling primarily with beach seines.

Model Analysis
Various models used to design tidally influenced restoration projects were evaluated. Available models include those based on empirical data and those based on numerical analyses. Criteria for selecting a model were presented in a matrix (Table B).

Table B. A matrix of key habitat parameters, associated restoration assessment techniques, and selection criteria for projects that could affect preferred habitats for tidewater goby.

Goby Habitat Parameter	Technique (*simple → very complex*)					
	Empirical Analysis		1D Numerical Modeling			2D Hydrodynamic Numerical Modeling
	Hydraulic Geometry	Inlet Stability Analysis	Sediment Deposition	Hydraulic Routing	Steady or Unsteady Flow	
Morphology	✖	✖				✖
Hydroperiod		✖		✖	✖	✖
Depth			✖	✖	✖	✖
Vegetation			✖	✖	✖	✖
Velocity				✖	✖	✖
Temperature and salinity					✖	✖
Substrate						✖
Criterion						
Data needs	(See Table 2)					
Considerations						
Limitations						

To improve understanding of tidewater goby populations, conceptual models should be further developed to provide a narrative description of the potential density-dependent and density-independent factors that affect each life stage of the tidewater goby. Linkages can then be explored between changing habitat conditions and the population response for specific life stages, first in conceptual models, and then, if feasible, in quantitative assessments using multi-stage stock-production population models.

Key questions that need to be addressed in future efforts include:

- Determination of specific limiting factors affecting tidewater goby life stages and duration of specific life stages. What biological factors (e.g., predation by natives and exotics) affect the population dynamics of tidewater goby at various scales, from site-specific to Recovery Units to their range in distribution? Similarly, what physical factors (e.g., depth, salinity, channel morphology) affect the population dynamics of tidewater goby?

- How do changes in the amount or quality of habitat (e.g., physical habitat, food availability) at critical life stages affect population resilience (i.e., ability to recover from a disturbance or population decline) of tidewater goby?
- To what extent can the abundance or resilience of the tidewater goby population in the reference area be increased through habitat enhancement?
- What are the special habitat features that must be protected to avoid tidewater goby population declines?
- What are the feasible enhancements and/or restoration options?
- What types of population models would be appropriate when density and abundance are so highly variable, even in apparently robust populations?

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Tables

1 INTRODUCTION

This document provides technical hydrologic and biologic guidelines to assist in the implementation of habitat restoration or enhancement activities for the federally listed tidewater goby (*Eucyclogobius newberryi*). The recent increase in attention to the tidewater goby is a result of the completion of the recovery plan (USFWS 2005) and increased interest and effort to restore brackish marshes and the lower reaches of streams around Humboldt Bay and other estuaries within the range of tidewater gobies in California. This document is being provided to the U.S. Fish and Wildlife Service (USFWS), other resource agencies, and local non-governmental organizations to assist in efforts to restore or enhance estuarine, lagoon and coastal freshwater habitats, particularly in the Humboldt Bay area.

With assistance from private restoration practitioners, resource agencies are seeking to restore wetland/estuarine habitats along the north coast of California, focusing on providing conditions that benefit native fish species listed under the Endangered Species Act. To date, restoration efforts have emphasized habitat improvement for native anadromous salmonids. Tidewater goby habitat requirements often overlap those of salmonids (e.g., brackish water marshes and other estuarine habitats). In some situations, habitat restoration may be mutually beneficial to salmonids and tidewater gobies. However, the habitat requirements of the tidewater goby differ enough such that restoration for salmonids may not always be beneficial to, and under some circumstances may be detrimental to, tidewater goby populations. Restoration and management of estuarine habitats will benefit from improved technical design standards and analysis methods that are not currently fully utilized, and that carefully consider each species' habitat needs through informed decision-making. The current emphasis on habitat restoration in estuarine systems provides a timely opportunity to incorporate goby technical data and recovery goals into ongoing and future restoration activities.

Through its Endangered Species Recovery Program, the USFWS funds research and development of technical information to assist its partners in recovering listed species through habitat restoration activities. Applied, science-based information is currently limited for restoration practitioners and agencies who design, evaluate, and fund goby recovery projects.

The development of guidelines and tools will facilitate restoration of tidewater goby habitats under a consistent set of science-based parameters for landowners and other parties interested in goby recovery. Consistent application of technical, detailed hydrologic and biological analyses will promote the efficient and timely restoration of degraded former habitats consistent with species' recovery goals. Without this information, restoration practices in estuarine habitats in the Humboldt Bay/Eel River area, and throughout the species range, will have a substantially lower likelihood of successful recovery of the tidewater goby, and may result in unnecessary conflicts with recovery goals for other listed fish species.

The guidelines within this report provide a "toolbox" or decision matrix of approaches for determining how a restoration project could affect hydrologic components of tidewater goby habitats. The approaches require and entail a range of data needs, costs, and expertise required to conduct evaluations. These guidelines are intended to complement recovery plans, and "the toolbox" can be used to evaluate how a restoration project could affect hydrology, water quality, salinity, and sediment transport, that in turn affect goby habitat conditions.

This report documents how one might use these guidelines as follows:

- Evaluation of tidewater goby habitat requirements.
- Evaluation of modeling techniques to design the restoration project (including a review of available models and how to select a model).
- Monitoring of restoration projects in tidally influenced areas.
- Identification of specific restoration scenarios and future needs affecting the tidewater goby.

2 EVALUATION OF TIDEWATER GOBY HABITAT REQUIREMENTS

The conceptual model for tidewater goby is that they are a small, short-lived, estuarine/lagoon adapted species that may infrequently disperse via marine habitat but with no dependency on marine habitat for its life cycle (Swift et al. 1989, Lafferty et al. 1999a). They can tolerate large temperature and salinity ranges (Swift et al. 1989, Tetra Tech 2000). They appear to require stable lagoon or off-channel habitats, particularly during their relatively short larval stage (Lafferty et al. 1999a, Chamberlain 2006).

Although tidewater goby are short-lived (generally 1 year), they have relatively high fecundity (females produce 300–500 eggs/batch and spawn multiple times per year), with males defending eggs in burrows. Tidewater goby are highly susceptible to predation by piscivorous fish and amphibians, especially introduced species. These predators include the sunfishes and basses (Centrarchidae), catfishes (Ictaluridae) in fresh water, striped bass (Moronidae) in estuaries, and African clawed frogs in some freshwater habitats (C. Swift, pers. comm., 2006, Lafferty et al. 1999a, and Swift et al. 1997, Lafferty and Page 1997, as cited in Moyle 2002). Introduced yellowfin goby and shimofuri goby may also compete with or prey on tidewater goby (Swenson and McCray 1996 and Swenson 1999, as cited in Moyle 2002). At least four species of Asian estuarine and freshwater gobies and the rainwater killifish (*Lucania parva*), have been introduced to California and may compete or displace tidewater goby when they occur in the same areas (C. Swift, pers. comm., 2006). Potential restoration projects for tidewater gobies should be evaluated for their potential to create favorable habitat conditions for introduced exotics. Tidewater goby appear to prefer brackish habitats some seasonally variable salinity over marine or freshwater conditions, potentially to avoid strictly marine or freshwater piscivores.

Tidewater goby appear to prefer shallow depths (< 1 m [3 ft]) near emergent vegetation, possibly to avoid predation by wading birds and piscivorous fish (Moyle 2002). Reported shallow minimum depths of occurrence may be associated with depth thresholds for wading bird predators such as herons; in general, avian predation efficiency decreases with depths > 20 cm (8 in) (Gawlik 2002). However, reported depth preferences may be biased because sampling equipment commonly used to survey tidewater gobies, such as beach seines, are limited in their utility to sample deeper habitats.

Persistence of tidewater goby populations is greatest in large wetlands. Distance between extirpated habitats and larger wetland source populations affects dispersal and potential for recolonization (Lafferty et al. 1999a and 1999b). Flood and breaching events can result in dispersal of tidewater gobies between estuarine/lagoon habitats, although survival is likely low and dispersal is limited. Gobies can persist in habitats that flood as long as a velocity refuge is present (Moyle 2002, Lafferty et al. 1999b). The life stages that are likely most sensitive to changes in habitat conditions associated with flooding and breaching are eggs in burrows and pelagic larvae (Chamberlain 2006).

Given this conceptual life history model, the first step in developing guidelines was to determine the habitat characteristics that best define the range most supported by the literature for tidewater goby over their various life stages. This was accomplished by reviewing the scientific literature (Appendix A) and evaluating extensive tidewater goby and environmental data from Lake Earl, located approximately 137 km (85 mi) north of Humboldt Bay, in Del Norte County (Appendix B); this abundant and persistent population is near the northern extreme of tidewater goby distribution.

Habitat characteristics were evaluated for tidewater goby in general, and more specifically when available, for spawning, juvenile, and adult goby life stages (Appendix A). Relevant information was summarized for a wide range of potential habitat parameters, including but not limited to:

- Habitat morphology
- Tidal influence (hydroperiod)
- Depth
- Velocity
- Temperature
- Salinity
- Dissolved oxygen
- Substrate
- Vegetation associations/cover types

In addition to the habitat parameters listed above, review of scientific literature indicated that other physical habitat characteristics could influence tidewater goby distribution and abundance in certain localities (Appendix A). Both qualitative and quantitative information was summarized; Quantitative information was separated and classified into minimum, maximum, mean, and optimal or preferred values when possible. The habitat parameters, summarized during the literature review, included a relatively broad range of values representing the range of conditions known to occur in habitats occupied by gobies (Appendix A). However, a narrower "preferred" range in habitat conditions is assumed to occur at locations where gobies have been found in greatest relative abundance, and where goby populations persist, as reported by the literature (Appendix A). Management or restoration should aim for "preferred" habitat conditions, with an understanding that the actual range that gobies can persist is greater than the preferred range.

The goal of the literature review was to narrow the range of habitat conditions that gobies appear to prefer. Although gobies appear to be tolerant of a wide range of habitat conditions, they appear to be most abundant and persist in habitats with a narrower range in habitat parameters during specific life stages as noted above. Additional considerations for evaluating restoration projects include the potential for (1) creating habitats supportive of goby predators, in particular non-native fishes and amphibians, and (2) degradation of habitat or water quality, in particular due to large-scale alterations that have occurred in large wetland habitats such as San Francisco Bay (Lafferty et al. 1999a).

Tidewater goby appear to depend upon seasonally disconnected (from the ocean) or tidally muted lagoons, estuaries and sloughs. The physical structure of tidewater goby habitat may be more important to goby persistence and survival than specific water quality characteristics such as temperature, salinity, and dissolved oxygen, based on the range of water quality parameters where gobies occur (Chamberlain 2006).

Reproduction and spawning typically occurs during spring and summer in slack shallow waters of seasonally disconnected or tidally muted lagoons, estuaries, and sloughs. Males dig burrows and guard eggs, peaking in early spring and late summer in some areas. Males in burrows and eggs, as well as larvae, are likely less tolerant of flood, breaching, or tidal exchange. Preferred reproduction/spawning water temperatures are 15–24°C (59–75°F) within a range of 2–27°C (36–81°F) as identified by the literature. Preferred salinities (ppt) for reproduction/spawning were identified as ≤ 15 within a range of 5–25. Preferred depths for tidewater goby reproduction/spawning were identified as 20–100 cm (8–39 in), however depth preferences reported in the literature are likely biased due to methods of sampling (e.g., beach seine). Substrate preferences appear to be sand, coarse sand, and sand/mud.

The preferred juvenile/adult habitat is also slack, shallow water in seasonally disconnected or tidally muted lagoons, estuaries, and sloughs. Flood refugia for juveniles/adults include "perched" habitats, off-channel sloughs, and pockets of still water. Juveniles and adults can be found year-round, although they are most abundant in summer/fall. Juvenile/adult life stages can tolerate flooding/breaching in late fall/winter provided adequate retention pools are available and estuarine conditions are established prior to the breeding season. Substrate preference is for sand, mud, gravel, and silt, particularly associated with submerged vegetation that is likely used for cover. Juvenile and adult tidewater goby do not appear to use purposeful burrows except during breeding, which may make these life stages very susceptible to predation. Juvenile/adult tidewater gobies were reported to prefer water temperatures of 12–24ºC (54–75°F) within a range of 5.8–25ºC (42–77°F). Salinities (ppt) preferred by juvenile/adults were reported to be ≤ 15 and within a range of 0–51. The literature indicates that preferred depths of juvenile and adult tidewater gobies range from 20–100 cm (8–39 in), based on sampling primarily with beach seines. However, gobies have recently been captured in Big Lagoon in water depths of up to 4.6 m (15 ft) using a small frame trawl towed by a small boat (C. Chamberlain, pers. comm., 2006).

3 EVALUATION OF MODELING TECHNIQUES USED TO DESIGN AND ASSESS RESTORATION PROJECTS WITHIN TIDAL ENVIRONMENTS

Once the desired goby habitat characteristics are identified, how to design and assess restoration projects is the next step. These guidelines next identify analytical tools and models that can assess how a restoration project affects the key habitats identified in step one. Restoration and/or creation of preferred habitat (as described above) within tidal environments requires consideration of many physical environmental variables, which are dependent on the site-specific conditions of the area of interest, the extent of the area to be restored, and project-specific restoration goals. For each variable relevant in designing a tidally influenced restoration project, several techniques can be used to determine the potential effects of the proposed restoration.

As described earlier, key habitat parameters to consider in decisions to manage, enhance, restore, or create preferred goby habitat include: (1) habitat morphology; (2) hydroperiod, which is the amount of time a marsh/wetland is inundated; (3) water depth; (4) vegetation type and extent; (5) water velocity; (6) temperature and salinity; and (7) substrate characteristics. The assessment techniques that address the effects that restoration may have on these key variables include: (1) empirical analysis (hydraulic geometry analysis and inlet stability analysis); (2) one-dimensional [1D] numerical modeling (sediment deposition analysis, hydraulic routing analysis, and steady/unsteady flow analysis); and (3) two-dimensional [2D] hydrodynamic numerical modeling. Three-dimensional [3D] models are utilized in tidal environments, however the application of these models can be very costly and typically beyond the scope of restoration projects, therefore 3D models are not considered here. Key goby habitat parameters and associated assessment techniques are presented in Table 1.

The techniques used to determine the effects of restoration of a tidal environment on preferred habitat range in scope from simple and economical to very complex and costly. More specifically, several techniques addressed require few data inputs that can be obtained cost-effectively while other techniques require several data inputs and model purchase and expertise that could be relatively cost-prohibitive (see Table 2). Because several techniques can be used for addressing a single key variable, the technique selected can be a function of several factors such as project funding, existing necessary resources, and more simply, use of the appropriate technique to get only the information that is needed for project-specific objectives.

The purpose of this section is to provide a description of the techniques and a general assessment of the appropriate application, requirements, and advantages/disadvantages of the techniques that can be used to address key variables relevant in restoring and/or creating tidewater goby habitat. This section describes the fundamental information pertinent to the types of analytical tools and numerical models that can be used when restoring and/or creating tidewater goby habitat. A comprehensive description of the specifics of available 1D and 2D numerical models (model capabilities, model strengths/limitations, model inputs and technical requirements) can be found in Appendix A to the Environmental Protection Agency (2005) technical report titled 'TMDL Model Evaluation and Research Needs.'

For all of the techniques described, a key limiting factor is the availability of long-term tidal data that are essential in determining the tidal elevations for the site, which are primary drivers for geomorphology, local hydraulics, local water quality conditions, the isolation regime or pattern of lagoon formation of the water body, and vegetation distribution dynamics.

Table 1. A matrix of key variables and associated restoration assessment techniques for projects that could affect habitats for tidewater goby.

Goby Habitat Parameter	Technique					
	Empirical Analysis		1D Numerical Modeling			2D Hydrodynamic Numerical Modeling
	Hydraulic Geometry	Inlet Stability Analysis	Sediment Deposition	Hydraulic Routing	Steady or Unsteady Flow	
Morphology	✖	✖				✖
Hydroperiod		✖		✖	✖	✖
Depth			✖	✖	✖	✖
Vegetation			✖	✖	✖	✖
Velocity				✖	✖	✖
Temperature and salinity					✖	✖
Substrate						✖

3.1 Empirical Analysis

3.1.1 Hydraulic geometry

Channels that are created or restored to tidal action as part of a restoration project will adjust in cross-sectional dimensions (width, depth, cross-sectional area) over time as a function of 1) marsh area or the tidal prism (volume of water that passes through the channel, between mean lower low water [MLLW] and mean higher high water [MHHW]), and 2) site-specific soil/vegetation conditions. Empirical relationships for equilibrium tidal channel hydraulic geometry (width, depth, cross-sectional area) as a function of marsh area and/or tidal prism have been developed for several tidal marshes. A detailed description of the form and derivation of these relationships can be found in Myrick and Leopold (1963) and Williams et al. (2002). These types of empirical relationships are simple to apply to estimate long-term morphologic changes in restored tidal channels with the anticipated change in tidal prism within the restored tidal channel.

Factors limiting the utilization of hydraulic geometry relationships include availability of tidal prism data and the availability of the appropriate empirical relationship for the restored channel. Tidal prism is determined from long-term values of MHHW and MLLW and the high-resolution topography of the site (required to estimate water volume in the marsh/channel between MHHW and MLLW). High-resolution spatial data can by obtained by ground surveys of elevation and aerial measurements from a fixed-wing aircraft (e.g., Light Detection And Ranging, or LiDAR, techniques). Ground surveys have the advantage of being cost-effective for smaller project areas; however, spatial coverage is usually limited. LiDAR can provide measurements of elevation over a large area with a relatively high degree of accuracy; however, obtaining LiDAR coverage for an area can be very costly (note: LiDAR data is becoming more readily available for regions throughout California, Oregon, and Washington). It should be noted that LiDAR data are appropriate for generating marshplain elevations and ground surveys are appropriate for obtaining elevations within tidal channels. The site-specific nature of existing empirical relationships for hydraulic geometry can also be limiting factors in determining equilibrium channel dimensions at a restoration site. For example, a restored channel within a pickleweed marsh may not have the same relationship between tidal prism and hydraulic geometry as a restored channel within a cordgrass marsh. Using the appropriate hydraulic geometry relationship for a restored tidal channel therefore required knowledge of the site-specific conditions for which the empirical relationship was derived.

3.1.2 Inlet stability analysis

Restored or created lagoon environments with a discrete connection to the adjacent tidal source (or inlet) may become disconnected from the tidal source when the inlet closes due to sediment being moved onshore by wave action. Similar to tidal channel hydraulic geometry, the hydraulic geometry of the inlet within a restored lagoon environment is a function of the contributing upstream (i.e., lagoon) tidal prism (Byrne et al. 1980; Vincent and Corson 1981). Within low-energy wave environments, inlets are likely to remain open as long as the tidal prism in the restored area is in a dynamic equilibrium with inlet dimensions. Within higher-energy wave environments, the stability of the inlet can be assessed through various relationships, including the ratio of tidal prism to the volume of sediment transported towards the mouth in one tidal period (Bruun 1978), the ratio of wave power to tidal power (O'Brien 1971), and the variation of maximum inlet velocity with minimum cross-sectional velocity as a function of the tidal prism-inlet area relationship (Escoffier 1977). A stability analysis of a tidal inlet is simple to apply and can provide an estimate of the hydroperiod of a restored or created tidal lagoon environment, on a seasonal and/or annual time scale as a function of inlet dimensions, tidal prism, longshore transport estimates, and wave/tidal power.

Factors limiting the use of an inlet stability analysis include the availability of tidal prism data and the availability of local tidal dynamics. As mentioned previously, high-resolution topographic data are needed to accurately assess tidal prism volume. High-resolution topographic data for a restoration site, if they do not already exist, can be very costly to obtain. Furthermore, the availabilities of long-term longshore transport estimates and local wave data can be limited, further complicating the assessment of the tidal inlet stability. The supply of sediment that is available to affect inlet closure is a function of the sediment supply from upcoast (i.e, longshore transport) and the ability for the sediment to deposit within the inlet (i.e., local wave dynamics). Both of these processes must be understood in order to make an accurate assessment of inlet closure dynamics.

3.2 1D Numerical Modeling

3.2.1 Sediment deposition

The elevations of restored tidal environments often increase due to suspended sediment which deposits during tidal inundation. An approach to quantifying marsh surface evolution as a function of suspended sediment deposition and tidal inundation has been developed by Krone (1987). In this approach, sediment deposition is calculated as a function of tidal elevation, initial marsh plain elevation, suspended sediment concentration, and particle settling velocity and marsh surface elevation rises at a rate dependent on availability of suspended sediment and water depth during periods of inundation. For example, if marsh elevation is low with respect to tidal elevation, the sedimentation rates could be relatively high due to the available deposition space and hydroperiod. However, as elevation increases, tidal inundation will decrease and sedimentation rates will also decrease. This approach has been adapted into simple numerical models and employed in several tidal restoration projects (PWA 2002a, 2002b). A comprehensive description of the derivation and form of the equations used within this type of analysis can be found in Krone (1987). A simple 1D sediment deposition model is more complex to apply than empirical relationships (i.e., requires knowledge of numerical modeling). However, it can be a useful tool in understanding of long-term marsh evolution and its associated changes in water depth and vegetation zonation, at a point location over a specified restoration time period.

A key factor limiting the utilization of sediment deposition modeling is the availability of elevation data for model calibration. Ideally, the model would be calibrated by knowing the depth of sediment accumulation over a known time period (with simple assumptions of time-averaged suspended sediment concentration and relative sea level rise). This calibration essentially allows for the derivation of suspended sediment concentration, which can then be used with the restored tidal signal to project the anticipated rate of future marsh elevation rise. However, the difficulty and cost of obtaining topographic data of the restoration site at two points in time (with sufficient time between elevation measurements to get a long-term average elevation increase) can limit the usefulness of sediment deposition modeling within tidal environments.

3.2.2 Hydraulic routing

Restored tidal environments can consist of a series of discrete water bodies that are connected by hydraulic structures (culverts, weirs, etc.). Within these environments, hydraulic routing models can be used to simulate flow from the tidal source into the pond nearest the source, and flow from the pond nearest the tidal source to the adjacent ponds through a network of hydraulic control structures. Water surface elevations are calculated as a function of pond elevation/storage capacity relationships, long-term tidal data, channel/hydraulic control structure characteristics, contributing watershed hydrographs, and initial pond water surface elevation. Model output includes a time series of water surface elevations within each pond, as well as velocity through the hydraulic control structures. A complete description of a model derivation and form can be found in Coats and Williams (1990) and PWA (2003). Use of a simple 1D hydraulic routing model is more complex than empirical analysis (i.e., requires knowledge of numerical modeling), but can be useful in determining the water depth dynamics and the associated anticipated vegetation dynamics within a tidal pond environment under restored tidal action for specific combinations of tide elevation and storm discharge.

Factors limiting the use of hydraulic routing models include the lack of availability of high-resolution topographic data, pre-restoration water surface elevation data for model calibration, and hydrograph data. These models require high-resolution topographic data, such as LiDAR data, for the elevation/storage capacity relationships; if these data do not already exist, obtaining them can be very costly. Hydraulic routing models also need to be calibrated under pre-restoration conditions, which may require installing and monitoring tide gages. If the adjacent watershed provides runoff, then data regarding storm-induced runoff magnitude and duration needs to be considered within the routing model. If these data are not readily available, then hydrographs would need to be synthesized numerically. Numerically modeling hydrograph data would require a high degree of numerical modeling expertise and knowledge about the characteristics of the contributing watershed (watershed size, roughness, flow routing characteristics, etc.).

3.2.3 Steady/unsteady flow routing

Understanding flow hydraulics through restored and/or created tidal channels can be critical in determining the quality and extent of restored tidal habitat. Several 1D numerical hydraulic models are available (e.g., HEC-RAS, MIKE11, RMA-11) that can provide daily, seasonal, and annual fluctuations in water depth, depth-averaged velocity, and depth-averaged temperature and salinity at longitudinal point locations along the longitudinal axis of a tidal channel. Flow hydraulic characteristics (water depth and depth-averaged velocity/shear stress) are determined as a function of cross-section characteristics, input hydrograph data, long-term tidal data, and hydraulic control structure characteristics. The flow hydraulic characteristics can be calculated, for steady (constant discharge) and unsteady (variable discharge) flow conditions under subcritical, supercritical, and mixed flow regimes, within and directly adjacent to tidal channels. These models can simulate the effects of various obstructions such as bridges, culverts, weirs, tide gates, spillways, levees, and other floodplain structures on flow dynamics. The MIKE11 model can accommodate looped networks and quasi two-dimensional flow simulations, and has been applied to simulate flow in environments ranging from steep rivers to tidally-influenced estuaries (DHI 2004). In addition to calculating flow hydraulics, 1D advection/dispersion (AD) modules are also available; these modules can simulate a time series of water quality parameters including salinity and temperature. Temperature and salinity are determined as a function of the flow hydraulic characteristics, initial depth-averaged salinity and water temperature, and local meteorological conditions. For a comprehensive explanation of the derivation of these types of numerical models, see Environmental Protection Agency (2005). Numerical hydraulic models can be very useful in determining water depth dynamics (and their associated anticipated vegetation dynamics), shear stress, and depth-averaged salinity and temperature within a restored or created tidal channel.

Factors limiting the use of steady/unsteady 1D hydraulic modeling include limitations of available numerical modeling expertise, available budget, the availability of calibration data, and the availability of hydrograph data. Using these types of hydraulic models requires advanced knowledge of the principles behind flow hydraulics as well as advanced knowledge of numerical modeling in tidal environments. Also, the use of the appropriate model depends on available project budget. Several models are free (HEC-RAS for example); however, they are not necessarily intended for tidal environments. Models designed for tidal environments (MIKE11, for example) can be quite costly (approximately $11,000 for the MIKE11 professional software package). Regardless of the model employed, the model should be calibrated with respect to water surface elevation and depth-averaged temperature and salinity under pre-restoration conditions, which generally require installing pressure transducers and collecting water samples. If hydrograph data sets for the contributing watershed do not exist, they would need to be numerically modeled, which would require a high degree of numerical modeling expertise and research on the characteristics of the adjacent and contributing watershed.

3.3 2D Hydrodynamic Numerical Modeling

Similar to1D numerical modeling, 2D hydrodynamic numerical modeling can be an extremely effective tool in determining the effects of restoration on flow hydraulics and water quality. Two-dimensional hydrodynamic modeling can provide daily, seasonal, and annual fluctuations in water depth, depth-averaged velocity, depth-averaged temperature and salinity, and sediment transport/deposition dynamics at point locations within a plane in a tidal environment. Hydraulic characteristics (water depth and depth-averaged velocity/shear stress) are determined as a function of cross-section characteristics, input hydrograph data, long-term tidal data, and hydraulic control structure characteristics. Several 2D numerical models (e.g., MIKE21, RMA/SED2D) can simulate unsteady depth-averaged flow dynamics. As with 1D numerical models, 2D numerical models can simulate the effects of various obstructions such as bridges, culverts, weirs, tide gates, spillways, levees, and other floodplain structures on flow dynamics, and additional modules can simulate time series of salinity and temperature in the same fashion as 1D models. Certain 2D numerical models are also capable of simulating sediment transport dynamics (scour and deposition) at points within the two-dimensional grid under the estuarine environment. Applying a 2D numerical hydraulic model can be useful in determining water depth dynamics (and the associated anticipated vegetation dynamics), shear stress, and salinity and temperature within a restored or created tidal channel as well as larger, more extensive tidal marsh environment.

Factors limiting the use of 2D hydrodynamic modeling include limitations of available numerical modeling expertise, available budget, the availability of calibration data, the availability of high-resolution topographic data, and the availability of hydrograph data. Use of 2D hydrodynamic models requires an extremely high level of expertise, which includes advanced knowledge of flow hydraulics and sediment transport, as well as a very advanced knowledge of numerical modeling within tidal environments. Purchase of 2D models can be very costly, and as running the 2D hydrodynamic models requires a high degree of expertise, 2D hydrodynamic modeling can be very expensive and should be utilized as dictated by project budgets and restoration objectives. These models should be calibrated with respect to water surface elevation, temperature and salinity, and suspended sediment concentration under pre-restoration conditions, which requires installing pressure transducers and collecting water samples. These models also require high-resolution topographic data, such as LiDAR, which, if these data do not already exist, can be very costly to obtain. If hydrograph data for the contributing watershed does not exist, it could be numerically modeled, which would require research on the characteristics of the adjacent and contributing watershed.

Table 2. A matrix of the data needs and considerations associated with various approaches to design and assessment of restoration projects within tidal environments.

Approach		Variable Addressed	Data Needs	Considerations/Limitations	Application
Empirical Analysis	Hydraulic Geometry	• Morphology	• Initial cross-section dimensions (top width, depth, cross-sectional area) • Tidal prism (long-term tidal data, topographic or bathymetric data)	• Site-specific empirical relationships • Availability of long-term tidal data and/or topographic/bathymetric data • Potential cost associated with topographic or bathymetric data	<u>SIMPLE</u> – long-term changes in channel dimensions associated with restoration
	Inlet Stability Analysis	• Morphology • Hydroperiod	• <u>Low-energy wave intensity</u> • Inlet dimensions (channel cross-section data) • Tidal prism (long-term tidal data, topographic/bathymetric data) • <u>Higher-energy wave intensity</u> • Inlet dimensions (channel cross-section data) • Tidal prism (long-term tidal data, topographic or bathymetric data) • Longshore transport estimates • Wave energy (wave height, wave direction) • Tidal power (?)	• Availability of long-term tidal data, longshore data, local wave data, and/or topographic/bathymetric data • Potential cost associated with topographic/bathymetric data collection	<u>SIMPLE</u> – hydroperiod on seasonal and annual timescale
1D Numerical Modeling	Sediment Deposition	• Depth • Vegetation	• Long-term tidal data • Topographic data • Sediment delivery rate • Effective and ambient suspended sediment concentration	• Availability of long-term tidal data and/or topographic or bathymetric data • Potential cost associated with topographic or bathymetric data collection • Validation data – need long-term change in topography to determine appropriate effective suspended sediment concentration • Simple assumptions about relationship between current and future suspended sediment concentration	<u>MORE COMPLEX</u> – long-term average sediment accumulation at a point location within a large tidal area

Approach		Variable Addressed	Data Needs	Considerations/Limitations	Application
1D Numerical Modeling (continued)	Hydraulic Routing	• Hydroperiod • Depth • Vegetation • Velocity	• Elevation/storage capacity relationship (high-resolution topographic data) • Long-term tidal data at the inlet • Channel/hydraulic control structure characteristics (dimensions, roughness estimates) • Watershed hydrograph • Initial water surface	• Availability of long-term tidal data, hydrology data, and topographic/bathymetric data • Potential cost associated with topographic/bathymetric data • Potential effort associated with constructing a hydrograph (i.e., additional hydrologic modeling) • Potential cost associated with calibration data – need to monitor water surface elevation data under existing conditions	<u>MORE COMPLEX</u> – maximum water surface elevation within a tidal area for specific tide elevation-storm event combination
	Steady/ Unsteady Flow	• Hydroperiod • Depth • Vegetation • Velocity • Temperature/ Salinity	• <u>Hydraulics</u> • Cross-section characteristics (dimensions and spacing, channel/floodplain roughness) • Input hydrograph • Long-term tidal data • Hydraulic control structures (dimensions, roughness) • <u>Temperature/Salinity</u> • Hydraulics data • Initial temperature • Meteorological data (wind speed, wind direction)	• Availability of long-term tidal data, hydrology data, meteorological, and topographic/bathymetric data • Potential cost associated with topographic or bathymetric data collection • Potential cost associated with model purchase • Potential effort associated with constructing a hydrograph (i.e., additional hydrologic modeling) • Potential cost associated with calibration data – need to monitor water surface elevation, salinity, and temperature data under existing conditions • High level of expertise needed for modeling	<u>COMPLEX</u> – daily, seasonal and, annual fluctuations in water depth, depth-averaged velocity, and depth-averaged temperature/salinity at point locations along a tidal channel

Approach	Variable Addressed	Data Needs	Considerations/Limitations	Application
2D Hydrodynamics Numerical Modeling	• Hydroperiod • Depth • Vegetation • Velocity • Temp/ Salinity • Substrate	• <u>Hydraulics</u> • High-resolution topographic data • channel/floodplain roughness • Input hydrograph • Long-term tidal data • Hydraulic control structures (dimensions, roughness) • <u>Temperature/Salinity</u> • Hydraulics data • Initial temperature • Meteorological data (wind speed, wind direction) • <u>Sediment transport/deposition</u> • <u>Sediment input rate</u> • Initial suspended sediment concentration • Critical velocity • Settling velocity • Erosion coefficient • Dispersion coefficient	• Availability of long-term tidal data, hydrology data, meteorological, and topographic/bathymetric data • Potential cost associated with topographic/bathymetric data collection (very high resolution data required) • Potential cost associated with model purchase • Potential effort associated with constructing a hydrograph (i.e., additional hydrologic modeling) • Potential costs associated with calibration data – need to monitor water surface elevation, salinity, and temperature data under existing conditions • Very high level of expertise needed for modeling • Potential cost associated with overall modeling effort	<u>VERY COMPLEX</u> – daily, seasonal, and annual fluctuations in water depth, velocity profiles, and temperature/salinity profiles at point locations within a grid in a tidal environment

4 MONITORING WITHIN RESTORATION PROJECTS IN TIDAL ENVIRONMENTS DESIGNED TO CREATE, RESTORE, OR ENHANCE TIDEWATER GOBY HABITAT

Project monitoring is essential to document the performance of any restoration project. In general, the habitat characteristics monitored should be based on project-specific goals and objectives, and the monitoring plan developed for any restoration project should consider: 1) the impact of monitoring on the restored habitat; 2) the selection of useful and appropriate reference sites; 3) collection of pre-restoration (baseline) data; and 4) establishment of scientifically-sound, testable hypotheses (NOAA 2003). The appropriate selection of reference sites against which project success can be appraised (either sites that have attributes similar to the restoration site or sites representing the ideal state to which the restoration site will be restored) is vital but can be significantly complicated by the inherent variability in both natural and restored systems (BMSL 2004). In addition, the functional parameters that describe coastal ecosystems are often not well understood (BMSL 2004). Within a project monitoring plan, testable hypotheses should be developed for each restoration goal identified, and data collection and analysis procedures for the parameters associated with each hypothesis should be clearly defined (NOAA 2003).

With regards to tidewater goby, several key habitat parameters were identified; these habitat parameters need to be considered within any restoration project aimed at restoring habitat for tidewater goby. Post-project monitoring of these parameters can be crucial in validating and updating the numerical models initially used to predict the effects of restoration. More generally, validating and updating the models will provide fundamental information for determining the success of restoration when compared to baseline and/or reference site data. For the key habitat parameters of the tidewater goby's habitat restoration, post-project monitoring elements include:

- Hydroperiod – tidal time scale and seasonal time scale assessment of how long the restored site is tidally inundated.
- Velocity – tidal time scale measurements of velocity within a restored tidal channel and/lagoon system.
- Depth – tidal time scale and seasonal time scale assessment of the depth of tidal inundation within a restored marsh and/or tidal channel. This is associated with sedimentation erosion/deposition and/or changes in channel morphology under restored conditions.
- Vegetation – assessment of changes in vegetation assemblage and distribution under restored conditions.
- Water quality – tidal time scale and seasonal time scale assessment of water quality parameters (salinity, temperature, dissolved oxygen, and turbidity) under restored conditions.
- Substrate – assessment of changes in substrate composition under restored conditions.

The frequency and duration of post-project monitoring are dependent on the processes being evaluated, site-specific characteristics of the restored site, and funds available for monitoring. In general, post-project monitoring should cover a time period that allows statistical evaluation of the change in the monitored key habitat parameter. The frequency of post-project monitoring can be divided into three phases: post-implementation, intermediate, and long-term (NOAA 2003). Post-implementation monitoring should focus on monitoring the key habitat characteristics that were directly manipulated as part of the restoration. When possible, intermediate years' monitoring (2 to 4 years after restoration) and long-term monitoring (occurring once the restoration project is on a defined trajectory) should focus on monitoring the structural components (i.e., the key habitat characteristics) as well as functional components (i.e., processes occurring within and between habitats as a result of their structural components) (NOAA 2003). For example, after a modification to a tide gate, sediment transport as evaluated by change in cross section profiles and thalweg mapping could occur in the fall, winter and spring post-implementation to evaluate tidal influence on sediment dynamics, and then again after the first two-year storm flow event, and again after the first five- and ten-year flow events when watershed inputs of sediment are expected to occur. These data need to be ground-surveyed in order to detect elevation changes due to sediment accumulation or erosion (i.e., re-measuring elevation with high resolution techniques such as LiDAR may not of acceptable due to the limits on vertical resolution). Conversely, salinity monitoring for a tide gate modification should occur during the first summer, fall, winter, and spring season post-implementation and not usually beyond, as it is expected that seasonal variability in salinity on goby habitat are likely to be greater than interannual variability.

In addition, habitat monitoring should be accompanied with biological monitoring of tidewater goby density and habitat use. The factors limiting tidewater goby populations should be evaluated in a hypothesis-based framework, rather than simply conducting routine monitoring, in order to:

- Improve our understanding of current and historical habitat conditions in lagoons and estuaries that support or historically supported tidewater goby,
- Develop and refine hypotheses about the factors limiting the production of tidewater goby,
- Develop recommendations for planning and implementation of restoration actions in specific lagoons/estuaries, and
- Develop recommendations for additional studies that can define cause-and-effect relationships between human land use activities in the estuary, lagoon, and watershed, and their impacts on water quality and tidewater goby habitat.

5 IDENTIFYING SPECIFIC RESTORATION SCENARIOS AND FUTURE NEEDS AFFECTING TIDEWATER GOBY WITHIN HUMBOLDT BAY

Since the onset of European settlement within the Humboldt Bay area, the bay-estuary and adjacent watershed ecosystems have been impacted considerably. Past modifications include installation of jetties to maintain an open bay entrance, dredging of the bay entrance for ship passage, and diking and draining "fringe" tidal marshes for agricultural and other development purposes. In an effort to off-set the negative environmental impacts of modification within the bay-estuary, resource agencies have increased funding for implementation of restoration efforts within Humboldt Bay over the past few years. To date, the main focus of restoration efforts has been native salmonids listed under the Endangered Species Act. The tidewater goby has habitat requirements that are similar to salmonids. However, goby habitat requirements differ to the extent that restoration of salmonid habitat may not be beneficial to, and in fact may negatively affect, the tidewater goby. Therefore, identifying specific restoration scenarios possibly affecting tidewater goby habitat, while designing restorations and writing monitoring plans, is crucial in determining the impacts of such practices as tide gate modification, and creation of brackish water and intertidal habitat.

Restoration scenarios potentially affecting tidewater goby habitat include:

- Tide gate modification for fish passage. Habitat preferences for tidewater goby include brackish water with very low velocity (e.g., seasonally disconnected lagoons, estuaries and tidal sloughs). Within tidal channel networks with tide gates, low velocity zones with sufficient depth to support tidewater goby populations can form in areas upstream of tide gates. Because tide gates are barriers for migrating native salmonids (and therefore a limiting factor for salmonid survival), restoration efforts within Humboldt Bay have included modifying tide gates to allow passage for in-migrating spawning adult and rearing juvenile salmonids and out-migrating salmonid smolts. These restoration efforts can potentially negatively impact tidewater goby populations because tide gate modification can increase local velocity (and associated shear stress) in habitats upstream of the tide gate, up to levels unsuitable for tidewater goby survival. Therefore, constraining the effects of tide gate modification on local velocity is essential in determining an appropriate tide gate design that will allow for salmonid fish passage as well as maintain suitable existing habitat for tidewater goby upstream of the tide gate. Sufficient off-channel, ponded, or perched habitat upstream of the tide gate may compensate for changes in local velocities associated with tide gate modifications.

- Restoration or enhancement of brackish water and intertidal habitat. Restoration and enhancement is a primary consideration within Humboldt Bay for increasing salmonid rearing habitat that has been lost to land management within the bay-estuary system. Because tidewater goby are found within brackish water habitat, creation of these environments can be mutually beneficial to both species. During reproduction/spawning, juvenile, and adult life stages, tidewater goby appear to prefer shallow depths (20–100 cm [8–39 in]) near emergent vegetation at the fringe of large estuaries and within lagoon and tidal slough systems. However, most previous surveys did not effectively sample in deeper waters, so tidewater gobies may also be found in deeper areas. Within restored brackish/tidal environments, water depth as a function of tidal inundation (i.e., hydroperiod) is a primary driver of sediment deposition dynamics (which in turn affects water depth) and both hydroperiod and salinity are the main controls on vegetation assemblage and zonation. Therefore, accurate prediction of both water depths and salinity dynamics within restored or enhanced brackish water environments is crucial in determining the long-term effect of restoration on tidewater goby habitat quality and extent.

Rather than addressing effects of individual restoration projects, a larger scale approach to restoring tidewater goby habitat needs to be considered (USFWS 2005). For example, the larger scale can be considered to be within Humboldt Bay, and persistence of the tidewater goby may not be feasible in the same habitats as salmonids. The potential for conflicts between salmonid and tidewater goby habitats are already evident and are likely to be exacerbated if projects continue to be evaluated on a site-by-site and a species-by-species basis.

To improve our understanding of tidewater goby populations, conceptual models should be further developed to provide an analysis and comparison of the potential density-dependent and density-independent factors that affect each life stage of the tidewater goby. Linkages can then be explored between changing habitat conditions and the population response for specific life stages, first in conceptual models, and then, if feasible, in quantitative assessments using life stage-specific stock-production population models.

Key questions that need to be addressed in future efforts include:

- Determination of specific limiting factors affecting tidewater goby life stages and duration of specific life stages. What biological factors (e.g., predation by natives and exotics) affect the population dynamics of tidewater goby at various scales, from site-specific to Recovery Units to their range in distribution? Similarly, what physical factors (e.g., depth, salinity, channel morphology) affect the population dynamics of tidewater goby?

- How do changes in the amount or quality of habitat (e.g., physical habitat, food availability) at critical life stages affect population resilience (i.e., ability to recover from a disturbance or population decline) of tidewater goby?
- To what extent can the abundance or resilience of the tidewater goby population in the reference area be increased through habitat enhancement?
- What are the special habitat features that must be protected to avoid tidewater goby population declines?
- What are the feasible enhancements and/or restoration options?
- What types of population models would be appropriate when density and abundance are so highly variable, even in apparently robust populations?

6 REFERENCES

BMSL (Battelle Marine Sciences Laboratory). 2004. National review of innovative and successful coastal habitat restoration. Technical report. Contract EA 1330-02-RQ-0029. Prepared for NOAA Coastal Service Center.

Bruun, P. 1978. Stability of tidal inlets. Elsevier Scientist Publishing Company, Amsterdam.

Byrne, R. J., R. A. Gammish, and C. R. Thomas. 1980. Tidal prism inlet area relations for small tidal inlets. Proceedings of the seventeenth Coastal Engineering Conference, American Society of Civil Engineers, Sydney, Australia. Volume III, Chapter 151: 23-28.

Chamberlain, C. D. 2006. Environmental variables of northern California lagoons and estuaries and the distribution of tidewater goby (*Eucyclogobius newberryi*). Draft technical report No. XX. U. S. Fish and Wildlife Service, Arcata Fish and Wildlife Office, Arcata, California.

Clewell, A. F., and R. Lea. 1990. Creation and restoration of forested wetland vegetation in the southeastern United States. Pages 195-231 *in* J. A. Kusler and M. E. Kentula, editors. Wetland creation and restoration: the status of the science. Island Press, Washington D. C.

Coats, R., and P. B. Williams. 1990. Hydrologic techniques for coastal wetland restoration illustrated by two case studies. Pages 236-246 *in* Environmental restoration: science and strategies for restoring the Earth. Island Press, Covelo, California.

DHI (Danish Hydrologic Institute). 2004. MIKE 11 - a modeling system for rivers and channels. Reference manual 513.

EPA (Environmental Protection Agency). 2005. TMDL model evaluation and research needs. Technical report. Contract 68-C-04-007. Prepared for the National Risk Management Research Laboratory.

Escoffier, F. F. 1977. Hydraulics and stability of tidal inlets. GITI Report 13, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Gawlik, D. E. 2002. The effects of prey availability on the numerical response of wading birds. Ecological Monographs 72: 329-346.

Krone, R. B. 1987. A method for simulating historic marsh elevations. In Proceedings of Specialty Conference on quantitative approaches to coastal sediment processes (Coastal Sediments 1987). New Orleans, Louisiana.

Lafferty, K. D., and C. J. Page. 1997. Predation on the endangered tidewater goby by the introduced African clawed frog, with notes on the frog's parasites. Copeia 1997: 769-780.

Lafferty, K. D., C. C. Swift, and R. F. Ambrose. 1999a. Extirpation and decolonization in a metapopulation of an endangered fish, the tidewater goby. Conservation Biology 13: 1447-1453.

Lafferty, K. D., C. C. Swift, and R. F. Ambrose. 1999b. Postflood persistence and recolonization of endangered tidewater goby populations. North American Journal of Fisheries Management 19: 618-622.

Moyle, P. B. 2002. Inland fishes of California. Revised edition. University of California Press, Berkeley.

Myrick, R. M., and L .B. Leopold. 1963. Hydraulic geometry of a small tidal estuary. USGS Professional Paper, 442-B. U. S. Government Printing Office, Washington, D. C.

NOAA (National Oceanic and Atmospheric Administration). 2003. Science-based restoration monitoring of coastal habitats. NOAA Coastal Ocean Program Decision Analysis Series.

O'Brien, M. P. 1971. Notes on tidal inlets on sandy shores. HEL 24-5. University of California Hydraulic Engineering Laboratory Report.

PWA (Philip Williams & Associates, Ltd.). 2002a. Morro Bay sedimentation: historical changes and sediment management opportunities to extend the life of the Bay. Technical report. Prepared for Central Coast Regional Water Quality Control Board.

PWA (Philip Williams & Associates, Ltd.). 2002b. Fir Island delta restoration feasibility study. Technical report. Prepared in cooperation with the Skagit System Cooperative for Skagit Watershed Council.

PWA (Philip Williams & Associates, Ltd.). 2003. Crescent Bay salt marsh and salmon habitat restoration plan. Technical report. Prepared in association with University of Washington Wetland Ecosystem Team (UW-WET) for Island County Public Works and Naval Air Station (NAS), Whidbey Island.

Swenson, R. O., and A. T. McCray. 1996. Feeding ecology of the tidewater goby. Transactions of the American Fisheries Society 125: 956-970.

Swenson, R. O. 1999. The ecology, behavior, and conservation of the tidewater goby, *Eucyclogobius newberryi*. Environmental Biology of Fishes 55: 99-114.

Swift, C. C., J. L. Nelson, C. Maslow, and T. Stein. 1989. Biology and distribution of the tidewater goby, *Eucyclogobius newberryi* (Pisces: Gobiidae) of California. Contribution Science. Natural History Museum of Los Angeles County, Los Angeles, California 404: 19 pp.

Swift, C. C., P. Duangsitti, C. Clemente, K. Hasserd, and L. Valle. 1997. Biology and distribution of the tidewater goby (*Eucyclogobius newberryi*) on Vandenberg Air Force Base, Santa Barbara County, California. Final report, USNBS Cooperative Agreement 1445-007-94-8129. U. S. National Biological Service.

Tetra Tech, Inc. 2000. Final report intensive habitat survey for Lake Earl and Lake Talawa, Del Norte County, California. Prepared by Tetra Tech, Inc., San Francisco, California for US Army Corps of Engineers, San Francisco District, San Francisco, California.

USFWS (U. S. Fish and Wildlife Service). 2005. Recovery plan for the tidewater goby (*Eucyclogobius newberryi*). U. S. Fish and Wildlife Services, Portland, Oregon.

Vincent, C. L., and W. D. Corson. 1981. The geometry of selected U. S. tidal inlets. Report 20. Army Corp of Engineers General Investigation of Tidal Inlets (GITI).

Williams, P. B., M. K. Orr, and N. J. Garrity. 2002. Hydraulic geometry: a geomorphic design tool for tidal marsh channel evolution in wetland restoration projects. Restoration Ecology 10: 577-590.

Appendix A

Tidewater Goby Habitat Criteria Tables

Table of Contents

Tables

1 UNSPECIFIED LIFE STAGE HABITAT

Table A-1. Velocity criteria for tidewater goby (general).

Velocity criteria				Source	Notes
Minimum	Maximum	Average	Preferred/ optimal		
				Swenson 1995 as cited in Swenson 1997	• "Tidewater gobies are intolerant of all but slow currents." • p. 8
				Swenson 1997	• San Gregorio and Pescadero creeks • "gobies were rarely collected from flowing waters or areas with strong wave wash and they appeared to avoid these conditions" • "gobies were absent from the main channel, which was flowing at 0.15 m/s (0.50 ft/s) (surface velocity), but were densely concentrated in an adjacent backwater pool." • "The availability of slack-water refuges, such as marshes and backwater areas of lagoons, may be critical during the winter rainy season." • p. 8
				Videler 1993 as cited in Tetra Tech Inc. 2000	• "...prefer slack-water habitats, perhaps to reduce energetic demands from swimming." • p. 8-2
				Irwin and Stolz 1984 as cited in Tetra Tech Inc. 2000	• "...prefer slow moving or fairly still but not stagnant water conditions." • p. 8-3

Table A-2. Depth criteria for tidewater goby (general).

Depth criteria				Source	Notes
Minimum	**Maximum**	**Average**	**Preferred/ optimal**		
			< 1 m (< 3 ft)	Swenson 1995 as cited in Swenson 1997	• San Gregorio and Pescadero creeks • "usually found in shallow water (< 1 m [3 ft] deep) close to shore • p. 9
25 cm (10 in)	100 cm (39 in)			Irwin et al. 1984 as cited in Tetra Tech Inc. 2000	• "Water depth in tidewater goby habitat ranges from 25 to 100 cm (10 to 39 in) where dissolved oxygen levels are fairly high." • p. 8-3
18 cm (7 in)	142 cm (56 in)		21–80 cm 8–32 in)	Tetra Tech Inc. 2000	• "Tidewater gobies were captured in sites with maximum water depths between 18 cm (7 in) and 142 cm (56 in), which represents the entire range of maximum depths sampled. The highest goby densities (>200 individuals/ square meters) observed were in sites with maximum depths between 21 cm (8 in) and 80 cm (32 in)." • Lake Earl and Lake Talawa • p. 8-11
		1–2 m (3–7 ft)		Swift et al. 1989 and Swenson 1995 both as cited in Capelli 1997	• "Tidewater gobies generally occur in 1 to 2 meters of standing water over a sandy or mixed sandy/silty bottom. They are weak swimmers, and generally avoid swiftly moving waters which can act has a velocity barrier preventing movement upstream oft the estuary." • p. 5
				Swenson 1996	• "We could not detect a strong correlation between goby density and depth, density of submerged aquatic vegetation, or substrate type. We collected and released 2,378 individuals. The range of densities measured was 0–14 gobies/m^2 collected with seine and 0–91 gobies/m^2 collected with throw traps. • Rodeo Lagoon • p. 7

Depth criteria				Source	Notes
Minimum	**Maximum**	**Average**	**Preferred/ optimal**		
	<1 m (3 ft)			Swift 1995	• "Tidewater gobies are usually collected in water less than 1 meter (3.3 feet) deep; many localities have little or no area deeper than this." • p. 4
	<1 m (3 ft)			Swift et al. 1989	• "Tidewater gobies occur on the substrate in loose aggregations of a few to several hundred individuals with no apparent size segregation. Fish move along the bottom in short spurts. Individuals occasionally hover in midwater along steep drop-offs or in dense aquatic vegetation. Except for adult males in the breeding season, fish do not burrow into the substrate in either nature or an aquarium. The escape mode is fleeing in long dashes (1-2 m [3–7 ft]) into deeper water or aquatic vegetation. Tidewater gobies were typically abundant in shallow water (≤ l m [3 ft] deep), but deep water was seldom sampled. However, many smaller lagoons have little or no water deeper than 1 m [3 ft]." • Aliso Creek • p. 6
				Irwin and Soltz 1984	• "...our observations indicate that tidewater gobies require still, but not stagnant pooled water. • San Antonio Creek
				Pinnix and Gray 2005 (unpublished data)	• Occurrence of tidewater goby and depth values for sample areas are summarized in Tables 1and 2 of Pinnix and Gray 2005 (unpublished data).

Table A-3. Salinity criteria for tidewater goby (general).

Salinity criteria				Source	Notes
Minimum	**Maximum**	**Average**	**Preferred/ optimal**		
			0–10 ppt	Swift et al. 1989 as cited in Swenson 1997	• Can tolerate a wide range of salinities • p. 7
0 ppt	30 ppt			Swift et al. 1989, Worcester 1992, and Swenson 1995 all as cited in Swenson 1997	• p. 7
	41 ppt			Swift et al. 1989 as cited in Swenson 1997	• Tolerated salinity based on laboratory experiments • p. 7
2 ppt	28 ppt			Swenson (n.d.) as cited in Tetra Tech Inc. 2000	• p. 8-2
			< 5.7 ppt, but also potentially higher than 12 ppt	Tetra Tech Inc. 2000	• "Salinity at the sampling sites ranged from 0.1 to 31.7 ppt. The majority of sampling sites contained salinity levels between 0 and 12 ppt. Goby densities greater than 50 individuals per site were observed where salinity levels were less than 5.7 ppt. There were very few sites observed with salinities higher than 12 ppt. However, some of these "higher salinity sites showed relatively high densities of goby. Since so few "higher salinity sites were sampled the observed densities cannot be considered representative." • Lake Earl and Lake Talawa • p. 8-11 to 8-12

Salinity criteria				Source	Notes
Minimum	**Maximum**	**Average**	**Preferred/ optimal**		
5 ppt	20 ppt		10–15 ppt	Capelli 1997	• "Estuaries which provide suitable Tidewater goby habitat exhibit a brackish water regime ranging from 5 to 20 ppt, with tidewater gobies displaying a preference for salinity levels between 10 and 15 ppt. Estuaries with a more permanent connection with the ocean have a more saline water regime (20 < 33 ppt) and often do not support tidewater gobies." • p. 2–3
		2–15 ppt		Swenson 1995 as cited in Swenson 1996	• "Common features of goby habitat include...low to moderate salinities (2–15 ppt)." • p. 2
			12 ppt	Swenson 1996	• "Seining in the lagoon produced 56 tidewater gobies (80% juveniles, < 27 mm [1 in] standard length). Seining upstream at the Southern Pacific Railway Bridge (near the Chevron pipeline site) produced one tidewater goby. At the Main Street Bridge further up the Ventura River, no tidewater gobies were collected during seining or observed during snorkeling. Salinity measured 12 ppt in the lagoon, 0–3 ppt at the pipeline site, and 0–3 at the Main Street Bridge." • Ventura River • p. 6
				Swenson 1996	• "Tidewater gobies were not collected by seining or tube trapping from the lower Big Sur River...and salinities were extremely low (approximately 0–1 ppt). Given that the mouth of the river never closes and no brackish lagoon forms, it appears that Big Sur River does not provide the appropriate habitat for tidewater gobies." • Big Sur River • p. 6

Salinity criteria				Source	Notes
Minimum	**Maximum**	**Average**	**Preferred/ optimal**		
			0–15 ppt	Swenson 1996	• "Four tidewater gobies were collected just below Mane Dam, the upper limit of tidal influence in San Luis Obispo Creek, but none downstream of this region. The two locations where tidewater gobies were found were characterized by very low salinity (0-1.5 ppt), virtually no current, and shallow water over a gradually sloping channel. All other sampling sites, which had no tidewater gobies, had either larger substrate (main channel was predominantly gravel) or higher salinity (lower part of stream)." • San Luis Obispo Creek • p. 7
				Swenson 1996	• "Three tidewater gobies were collected and released in Toro Creek Surprisingly, none were collected in the lagoon. Salinity measured 1 ppt in all locations, except at the mouth, where occasional wave wash brought the salinity up to 12 ppt." • Toro Creek • p. 7
				Swift 1995	• "Most collections are from water one-third sea salinity, or about 12 parts per thousand or less." • p. 4
0 ppt	42 ppt		<10 ppt	Swift et al. 1989	• "All sizes of tidewater goby usually occur at the upper end of lagoons at salinities ≤ 10 ‰. 0f 60 collections 39 were at 0–10 ‰, 12 at 10-20 ‰, 10at 20–30 ‰, and one at 42 ‰, the last in Bennett Slough, a tributary of Elkhorn Slough, Monterey County." • Aliso Creek • p. 7

Salinity criteria				Source	Notes
Minimum	**Maximum**	**Average**	**Preferred/ optimal**		
				Hubbs 1947 and Fierstine et al. 1973 both as cited in Swift et al. 1989	• "Records of ≤10 ‰ are given by Hubbs (1947) and Fierstine et al. (1973)." • p. 7
				Bell 1979 as cited in Swift et al. 1989	• "Fish from 20–25 and 30 ‰ in Corcoran Lagoon, Santa Cruz County, are reported by Bell (1979)." • p. 7
	41 ppt			Swift et al. 1989	• "In the first salinity tolerance experiment (see Methods), all fish from 60.0, 70.8, and 81.6‰ expired in six hours; at 48.6‰ all fish expired in 24hours. Those in fresh water (control), 18‰, and 35.4‰ all survived for 25 days." • "In the second experiment, 80‰ of fish at 50.7‰ expired in 24 hours, and the two remaining fish died in nine days. All the fish at 45.5‰ died in six days, and 80-100% of the fish at 35.0, 36.75, and 40.25‰ survived 22 days, as did controls at 13.2‰." • "In the third experiment, two groups of fish experienced a gradual rise in salinity due to evaporation for 53 days. One group began at 16.2‰, the other at 40.2‰. At the end, salinity was 25.2‰ and 61.8‰, respectively. Survival was 75‰ and 59‰ , respectively, with the die-off of fishes widely scattered over this time interval." • "Experimental groups of fish in salinities above 41‰ experienced high mortality. In the third long experiment with slow change in salinity, over half the fish survived hypersaline conditions (up to 1.75 times that of seawater). Controls in fresh water survived up to 84 days from time of collection." • p. 7

Salinity criteria				Source	Notes
Minimum	**Maximum**	**Average**	**Preferred/ optimal**		
				Irwin and Soltz 1984	• Occurrence of fish species and salinity values for sample areas are summarized in Tables 1–4 of Irwin and Soltz 1984.
				Pinnix and Gray 2005 (unpublished data)	• Occurrence of tidewater goby and salinity values for sample areas are summarized in Tables 1and 2 of Pinnix and Gray 2005 (unpublished data).
			< 5 ppt	Wang and Keegan 1988 as cited in Chamberlain 2006	
			< 10 ppt	USFWS 1994, 2000, and 2002 all as cited in Chamberlain 2006	
			0 to 10 ppt	Swenson 1999 as cited in Chamberlain 2006	
			< 12 ppt	USFWS 2005 as cited in Chamberlain 2006	
	27 ppt			Worcester 1992 as cited in Chamberlain 2006	• From Table 1, p. 3: Tolerant 0-41 ppt (Swift et al. 1989); Observed up to 27 ppt (Worcester 1992); Observed 2-27 ppt (Swenson 1995); Observed 1-28 ppt (Swenson and McCray 1996); Tolerant up to 54 ppt (Worcester and Lea 1996); Suitable 5-20 ppt (Capelli 1997); tolerant freshwater to 51 ppt (USFWS 2000); Suitable up to 28 ppt (USFWS 2005)

Salinity criteria				Source	Notes
Minimum	**Maximum**	**Average**	**Preferred/ optimal**		
2 ppt	27 ppt			Swenson 1995 as cited in Chamberlain 2006	See notes for Worcester 1992 as cited in Chamberlain 2006
1 ppt	28 ppt			Swenson and McCray 1996 as cited in Chamberlain 2006	See notes for Worcester 1992 as cited in Chamberlain 2006
	54 ppt			Worcester and Lea 1996 as cited in Chamberlain 2006	See notes for Worcester 1992 as cited in Chamberlain 2006
0 ppt	51 ppt			USFWS 2000 as cited in Chamberlain 2006	See notes for Worcester 1992 as cited in Chamberlain 2006
	28 ppt			USFWS 2005 as cited in Chamberlain 2006	See notes for Worcester 1992 as cited in Chamberlain 2006
0.1 ppt	37.8 ppt		<10 ppt	Chamberlain 2006	• "At the extremes of water quality as measured near the substrate, tidewater goby were found in salinities that included fresh 0.1 and hypersaline 37.8 ppt water." • p. 13 • Figures 19 and 20 indicate that gobies occurred at the highest densities at salinities < 10 ppt. • P. 33 and 34

Table A-4. Temperature criteria for tidewater goby (general).

Temperature criteria				Source	Notes
Minimum	**Maximum**	**Average**	**Preferred/ optimal**		
9°C (48°F)	25°C (77°F)			Swift et al. 1989, Worcester 1992, and Swenson 1995 all as cited in Swenson 1997	• p. 7
5.8°C (42°F)	24.0°C (75°F)		12–24°C (54–75°F)	Tetra Tech Inc. 2000	• "During the course of this study, temperatures within the sample sites ranged from 5.8 to 24°C [42–75°F]. Tidewater goby were captured at nearly all temperatures within that range. Sites with temperatures between 12 and 24 °C [54 and 75°F] showed the highest densities, especially during spawning season." • Lake Earl and Lake Talawa • p. 8-12
				Irwin and Soltz 1984	• Occurrence of fish species and temperature values for sample areas are summarized in Tables 1–4 of Irwin and Soltz 1984.
				Pinnix and Gray 2005 (unpublished data)	• Occurrence of tidewater goby and temperature values for sample areas are summarized in Tables 1and 2 of Pinnix and Gray 2005 (unpublished data).
8.5–9°C (47–48°F)	27°C (81°F)			Irwin and Soltz 1984, Wang 1984, and Swift et al. 1989, all as cited in Chamberlain 2006	• "General habitat characteristics reported in the literature include:...temperatures ranging from 8.5-9°C [47–48°F] in winter (Wang 1984; Swift et al. 1989) to 27°C [81°F] in summer (Irwin and Soltz 1984)." • p. 2

Temperature criteria				Source	Notes
Minimum	Maximum	Average	Preferred/ optimal		
13.0°C (55°F)	25.4°C (78°F)			Chamberlain 2006	• "At the extremes of water quality as measured near the substrate, tidewater goby were found in..temperatures at 13.0 and 25.4 ºC [55 and 78°F]." • p. 13
				Chamberlain 2006	• "Tests of tidewater goby density against each of the water quality parameters yielded no results significant at α= 0.05. With its emphasis in much of the tidewater goby literature, I expected salinity more than any of the other parameters to have an influence on tidewater goby density. Surface salinity was not useful for explaining tidewater goby density ($p = 0.55$). Likewise, no relationship was revealed between density and bottom salinity or any of the other water quality parameters top or bottom." • p. 32, samples July-Oct 1996, N. California

Table A-5. Other potential factors influencing tidewater goby (general).

Source	Notes
	STREAM FLOW/FLOODING
Lafferty et al. 1999a	• "Stream flow, date and wetland size explained only a portion (12%) of the variation in goby population dynamics." • "Management of both small and large wetlands should include maintaining natural stream flows, protecting sand barriers at the mouths of lagoons, monitoring water quality, preventing the spread of exotic species and reintroduction." • p. 1,452
Lafferty et al. 1999b	• "Perhaps individuals burrow to escape moderate flow or move laterally to find pockets of still water associated with vegetation and debris. Evidently, this is possible even in small streams with steep banks." • "Instead of being threats, floods may be important to the long-term persistence of the tidewater goby across its range. • p. 621

Source	Notes
	HYDROPERIOD/ TIDAL FLUCTUATIONS
Swenson 1997	• "Repeated disturbance from frequent breaching events could jeopardize food supplies for tidewater gobies in lagoon habitats." • p. 17
Capelli 1997	• "Where the build up of a seasonal sand and cobble berm creates a brackish water regime throughout the estuary, tidewater gobies may utilize the entire estuary, including vegetated backwater areas. In larger estuaries with prolonged exposure to tidal action tidewater gobies are generally restricted to the upper reaches of the estuary near the freshwater-saltwater interface." • p. 3
Swift et al. 1989 and Smith 1990 both as cited in Capelli 1997	• "Under natural conditions estuarine water levels during the late spring through early winter months remain relatively stable as a result of a balance between upstream freshwater inflow, evaporation, and percolation through the porous sand and cobble berm. Occasional surf washing over the berm during the summer and fall, along with percolation of marine water through the berm into the estuary, also helps sustain the mildly brackish water regime preferred by the tidewater goby." • p. 4
Shapovalov and Taft 1954, Swift et al. 1989, Josselyn et al. 1990, and Smith 1990 all as cited in Capelli 1997	• "These seasonal variations in freshwater inflow from rivers and stream during the spring, summer, fall, and winter months, coupled with changes in the wave climate and mixed semi-diurnal variations in tides, results in the prolonged closure of most California estuaries to the ocean. The closure of the estuary during the late spring, summer and fall months and the gradual conversion of the estuary from a marine to a low salinity brackish water regime creates a maximum amount of suitable spawning and rearing habitat for the tidewater goby." • p.4
Capelli 1997	• "In several instances tidewater gobies in artificially created tidal conditions have become extirpated after a few years of exposure to continuous tidal flushing." • p. 8
Swift et al. 1989, Smith 1990, Swenson 1995, and Worcester 1992 all as cited in Capelli 1997	• "The life-cycle of the tidewater goby is adapted to the natural seasonal breaching cycles of estuaries but can be disrupted by artificial breaching, particularly during the spring and summer. Breaching results in immediate reduction in the depth and aerial extent of the estuary. Because the water level in closed California estuaries is generally several feet above mean sea-level, and as much as 6 feet [2 m] above lower-low mean sea-level, breaching can result in the complete draining of the estuary. Sudden lowering of water levels can sweep tidewater gobies into the marine environment, or strand fish in shallow pools or on exposed substrates, increasing their vulnerability to predation by shore and other water birds. The sudden artificial breaching of the estuary mouth, unlike natural breaching in response to rainfall and increased runoff, provides no natural cues which may allow tidewater gobies to seek refuge in backwater or marginal areas of the estuary. The artificial draining of a closed estuary in late spring or summer may result in the estuary being dominated by marine water for extended periods until winter run-off increases the inflow of freshwater into the estuary.

Source	Notes
	Marine water is denser than freshwater and will dominate the lower depths of the estuary directly over the substrate where tidewater gobies congregate. This marine water acts as a solar collector heating up and reducing oxygen levels, and thus providing sub-optimal or lethal conditions for the tidewater goby. The sudden influx of marine water as a result of artificial breaching can also sharply reduce the abundance of non-marine invertebrates which provide the primary food source for the tidewater goby. Artificially breaching the estuary during the spring, summer and fall seasons can adversely affect the reproductive and rearing life-history phase of the tidewater goby. Lowering of water levels can expose juveniles and incubating eggs in breeding burrows to the air, leading to desiccation and death (Smith 1990; Swenson 1995; Swift et al. 1989). Recent research provides evidence that vegetated areas at the margins of the estuary serve as refugia for rearing tidewater gobies. These areas can become isolated from the main water body of an estuary as a result of artificial breaching and draining, thus depriving tidewater gobies of productive rearing sites and effective protection from predators (Swenson 1995; Worcester 1992)." • p. 9–10
Pinnix and Gray 2005 (unpublished data)	• Occurrence of tidewater goby and tidal level for sample areas are summarized in Tables 1 and 2 of Pinnix and Gray 2005 (unpublished data)
Chamberlain 2006	• "Tidewater goby were not detected in any of the seven fully tidal waters sampled. Nor did I detect any in Freshwater Lagoon which has had no connectivity to tidal influence since construction of Highway 101 on its sandbar, and where the last documented record of the species dates back to 1951. Tidewater goby were detected in 12 of the 16 waters with partial or full seasonal closure." • "Tidewater gobies were most abundant during this study in lagoons/estuaries without a tidal influence at the time of sample and with relatively homogenous water quality between sample sites, seemingly regardless of what that water quality was. I found tidewater goby only in low abundance if at all in estuaries where the mouth was frequently open to the ocean; and in those cases where they were detected in frequently open estuaries, I found them in a limited range within those waters." • p. 43, samples July-Oct. 1996, northern California
VEGETATION ASSOCIATIONS (SPECIES, ETC)	
Swenson 1997	• "Tidewater gobies occurred both over unvegetated substrate, and in areas with submerged vegetation." • p. 9
Videler 1993 as cited in Tetra Tech Inc. 2000	• "Adults also preferred areas with some vegetation, such as either pondweed (*Potamageton* spp.) or submerged terrestrial vegetation." • p. 8-2

Source	Notes
Tetra Tech Inc. 2000	• "...the results of this study showed no discernable preference. However, it should be noted that the sample containing the highest density of goby (312 individuals, 101 of which were gravid females) observed was taken in a site that was 100% vegetated." • Lake Earl and Lake Talawa • p. 8-12
Swenson 1996	• "We could not detect a strong correlation between goby density and depth, density of submerged aquatic vegetation, or substrate type. We collected and released 2,378 individuals. The range of densities measured was 0–14 gobies/m^2 collected with seine and 0–91 gobies/m^2 collected with throw traps. • Rodeo Lagoon • p. 7
Swift et al. 1989	• "Tidewater gobies occur on the substrate in loose aggregations of a few to several hundred individuals with no apparent size segregation. Fish move along the bottom in short spurts. Individuals occasionally hover in midwater along steep drop-offs or in dense aquatic vegetation. Except for adult males in the breeding season, fish do not burrow into the substrate in either nature or an aquarium. The escape mode is fleeing in long dashes (1-2 m [3–7 ft]) into deeper water or aquatic vegetation." • Aliso Creek • p. 6
Pinnix and Gray 2005 (unpublished data)	• "The length of Gannon Slough from Site 3 to Site 10 was walked and tidewater gobies were observed throughout the length of the brackish portion of the slough. Gobies were seen in densities of approximately1-3 fish/m^2 from Site 3 to Site 9 and were seen near burrows. The banks of this channel have rooted vegetation, but little vegetation (approximately 10% canopy coverage) is rooted in the channel." • p. 1
Lafferty et al. 1999a	• "persistence of tidewater goby populations was affected by wetland size and annual variation in stream flow. In small wetlands, tidewater gobies did better in wet than in dry years. Wet hears led to a larger usable habitat area, better water quality, and perhaps most important, a lower chance of drying up. Conversely, variation in stream flow had little effect in large habitats, even in dry years. The restriction of local populations to single wetlands, coupled with the limited ability of individuals to move voluntarily to more favorable habitats, made goby populations in small wetlands especially susceptible to environmental stochasticity, particularly droughts. Unfortunately for the goby, the time it needs to leave a habitat – during a drought – is when it is least able to leave. Thus, large wetlands probably provided a persistent refuge even during unfavorable conditions." • "Stream flow, date and wetland size explained only a portion (12%) of the variation in goby population dynamics." • "Management of both small and large wetlands should include maintaining natural stream flows, protecting sand barriers at the mouths of lagoons, monitoring water quality, preventing the spread of exotic species and reintroduction." • p. 1,451

Source	Notes
Trihey and Associates 1996 as cited in Chamberlain 2006	• Trihey and Associates (1996) found gobies to be most abundant over a mucky substrate and in submerged aquatic vegetation. • p. 2
Chamberlain 2006	• "Dominant substrates and vegetation were likewise variable with tidewater goby detected on everything from anoxic muck and mud to rock, and in habitats void of vegetation to those with emergent aquatic vegetation thick enough to make even dip-net sampling a challenge." • p. 13, sampled July-Oct. 1996, N. California
Chamberlain 2006	• "Because sample sites were selected partially based on their suitability to be fished with a beach seine, I caution the reader in interpretation of substrate and vegetation results from this study. Almost without exception, the sample sites occurred at the shoreline of the water bodies visited as waters away from shore were usually too deep to wade and not practical to sample. Even the shorelines of many locations were largely un-fishable; much of the Lake Earl shoreline for instance was dominated by impenetrable bulrush *Scirpus spp*.; and widgeon grass *Ruppia maritima* at times occupied large portions of the deeper water where fish sampling would not have been effective with the gear types I employed. These thickets of vegetation likely harbored tidewater goby but were not sampled. Because of the above concerns, the frequency distribution of sampled substrate and vegetation types should not be considered representative of the distribution of these variables in the available habitats." • "Among 1996 sample sites in those water bodies where tidewater goby presence was confirmed, bare substrate was the dominant vegetation type in 25 of 43 (58%), followed by filamentous algae (30%) and rooted vascular (12%). The incidence of bare substrate was even higher at 83% (34 of 41) for those sites where tidewater goby were not found, followed by filamentous algae (15%) and rooted vascular (3%). But the sampled substrate distributions were not significantly different between water bodies with and without tidewater goby detection (Fisher's exact test; $p = 0.27$), or among "present" and "absent" sample sites within tidewater goby positive waters (Fisher's exact test; $p = 0.06$)." • p. 35, sampled July-Oct. 1996, N. California
HABITAT TYPES	
Swenson 1995 as cited in Swenson 1997	• "sandy lagoons, mud or mud and gravel-bottomed reaches of creeks, and muddy marsh pools and channels." • San Gregorio and Pescadero creeks • p. 7 and 9
Videler 1993 as cited in Tetra Tech Inc. 2000	• "...prefer slack-water habitats, perhaps to reduce energetic demands from swimming." • p. 8-2

Source	Notes
Chamberlain 2006	• "In recent sampling around Humboldt Bay, the Arcata Fish and Wildlife Office has discovered tidewater goby in “perched” off-channel habitats (unpublished data). These habitats are reached by very high tides, but are discontinuous with the bay at times and potentially afford larval goby periodic opportunity to mature to benthic stage without exposure to entrainment. There are likely other benefits to tidewater goby from these off channel habitats such as refuge from predation and increased food availability (Swenson 1995, 1999; Swenson and McCray 1996; Capelli 1997)." • p. 44
SUBSTRATE	
Swenson 1997	• San Gregorio and Pescadero creeks • The author notes that observations of goby feeding behavior suggest that they have adaptive foraging behavior depending on available substrate types. • p. 16–17
Tetra Tech Inc. 2000	• "Tidewater gobies were found to use both silt and sand substrates habitats within the lagoon." "...higher densities of goby being captured in sites with predominantly silt substrate...this likely reflects the predominance of silt substrate available in the lagoon rather than any preference by tidewater goby." • Lake Earl and Lake Talawa • p. 8-12
Swift et al. 1989 and Swenson 1995 both as cited in Capelli 1997	• "Tidewater gobies generally occur in 1 to 2 meters [3 to 7 ft] of standing water over a sandy or mixed sandy/silty bottom. They are weak swimmers, and generally avoid swiftly moving waters which can act has a velocity barrier preventing movement upstream oft the estuary." • p. 5
Swenson 1995 as cited in Swenson 1996	• "Common features of goby habitat include...fine sediment such as sand, mud, or muddy gravel." • p. 2
Swenson 1996	• "Tidewater gobies were not collected by seining or tube trapping from the lower Big Sur River. The substrate was sand and gravel." • Big Sur River • p. 6
Swenson 1996	• "Seining in the lagoon produced 56 tidewater gobies (80% juveniles, < 27 mm standard length). Seining upstream at the Southern Pacific Railway Bridge (near the Chevron pipeline site) produced one tidewater goby. At the Main Street Bridge further up the Ventura River, no tidewater gobies were collected during seining or observed during snorkeling. The substrate was sand with a little silt in the lagoon and near the pipeline. At the Main Street Bridge the substrate included gravel, silt and sand. Currents were stronger at the Main Street Bridge, but often slack in the lagoon and parts of the pipeline site." • Ventura River • p. 6

Source	Notes
Swenson 1996	• "Four tidewater gobies were collected just below Mane Dam, the upper limit of tidal influence in San Luis Obispo Creek, but none downstream of this region. The two locations where tidewater gobies were found were characterized by coarse sand. All other sampling sites, which had no tidewater gobies, had either larger substrate (main channel was predominantly gravel) or higher salinity (lower part of stream)." • San Luis Obispo Creek • p. 7
Swenson 1996	• "We could not detect a strong correlation between goby density and depth, density of submerged aquatic vegetation, or substrate type. We collected and released 2,378 individuals. The range of densities measured was 0–14 gobies/m^2 collected with seine and 0–91 gobies/m^2 collected with throw traps. • Rodeo Lagoon • p. 7
Swenson 1996	• "Three tidewater gobies were collected and released in Toro Creek. Surprisingly, none were collected in the lagoon. The substrate was predominantly sandy, with some gravel mixed in at the upstream location where gobies were found." • Toro Creek • p. 7
Swift 1995	• "The species often invades upstream into tributaries up t o 0.5 t o 1.0 kilometer (one third to a little more than half a mile). Little or no evidence of reproduction in these upper areas is apparent." • p. 4
Swift 1995	• "All size classes are substrate oriented and little segregation by size has been noted." • p. 6
Pinnix and Gray 2005 (unpublished data)	• "The length of Gannon Slough from Site 3 to Site 10 was walked and tidewater gobies were observed throughout the length of the brackish portion of the slough. The habitat in this lower section (sites 2-9) is a layer of mud/sand approximately 6 inches [15 cm] deep over a sand/gravel substrate in a channel approximately 2-4 meters [7–13 ft] wide." • p. 1
Trihey and Associates 1996 as cited in Chamberlain 2006	• Trihey and Associates (1996) found gobies to be most abundant over a mucky substrate and in submerged aquatic vegetation. • p. 2
Chamberlain 2006	• "Dominant substrates and vegetation were likewise variable with tidewater goby detected on everything from anoxic muck and mud to rock, and in habitats void of vegetation to those with emergent aquatic vegetation thick enough to make even dip-net sampling a challenge." • p. 13

Source	Notes
Chamberlain 2006	• "Sand and mud were the most frequent dominant substrates recorded across all 1996 samples (40% and 36% respectively). Sand was a bit more frequent at locations with tidewater goby detection (44% vs. 33%), but the differences in dominant substrate distributions were not significant between waters with and without positive tidewater goby detection (Fisher's exact test, p = 0.30). Nor were dominant substrate classifications significantly different among "present" and "absent" sample sites within tidewater goby positive waters (Fisher's exact test; p = 0.56)." • p. 35
DISSOLVED OXYGEN	
Tetra Tech Inc. 2000	• "DO in the sites sampled ranged from 0.53 to 14.87 milligrams per liter (mg/l). Tidewater goby were captured throughout this range and although higher densities were observed at DO levels between 2 and 4 mg/l, not enough samples were collected in this range to indicate preference." • Lake Earl and Lake Talawa • p. 8-11
Swift 1995	• "Additional features required by the tidewater gobies are areas of coarse, well oxygenated, sandy substrate in water less than 1 meter [3 ft] deep, and good quality water. Water quality criteria cannot be specific at this time. While tidewater gobies are known to tolerate a wide variety of salinities (Swift et al. 1989) and seem tolerant of "polluted" waters (Ambrose and Lafferty 1993; Camm Swift, personal observation), the exact tolerances are not known. Even anoxia in lagoons, probably caused by nutrient loading, can be tolerated to some extent utilizing aerial respiration (Camrn Swift, personal observation).On the other hand, such anoxia may be fatal to eggs in burrows. Until such tolerances can be determined, water quality standards for other fishes like stickleback, rainbow trout, and prickly sculpins, common associates of tidewater gobies, should be sufficient." • p. 45
Irwin and Soltz 1984	• Occurrence of fish species and DO values for sample areas are summarized in Tables 1–4 of Irwin and Soltz 1984
Irwin and Soltz 1984 as cited in Chamberlain 2006	• "General habitat characteristics reported in the literature include:...dissolved oxygen concentrations of 4–19 mg/l (Irwin and Soltz 1984)." • p. 2
Capelli 1997 as cited in Chamberlain 2006	• "Reduced oxygen levels suboptimal (Capelli 1997)" • Table 1, p. 3
Moyle 2002 as cited in Chamberlain 2006	• "Well oxygenated water required and tidewater goby disappear from lagoon areas that stagnate or stratify (Moyle 2002)" • Table 1, p. 3

Source	Notes
Swift et al. 1994 as cited in Chamberlain 2006	• May be able to breath air and survive anoxic events (Swift et al. 1994) • Table 1, p. 3
USFWS 1999 as cited in Chamberlain 2006	• Tolerant of low levels (USFWS 1999) • Table 1, p. 3
Chamberlain 2006	"By far, the highest densities of tidewater gobies were captured at Rodeo Lagoon. In one 3 m [10 ft] seine haul there, over 1,500 tidewater goby were captured! Water quality conditions were very anoxic with several dissolved oxygen measurements of less than 1.0 mg/l. Densities were potentially elevated along the margins because of the extremely low oxygen levels." • p. 12
Chamberlain 2006	• "At the extremes of water quality as measured near the substrate, tidewater goby were found in...concentrations of dissolved oxygen at 0.2 and 15.5 mg/l." • p. 13
MINIMUM HABITAT AREA	
Swift et al. 1989, Ballard and Swift 1996, and Swenson 1995 all as cited in Capelli 1997	• "Estuaries supporting tidewater gobies vary in size from a few square meters to several square kilometers. Today most estuaries supporting Tidewater gobies are small, ranging from approximately 1 to 2 hectares [2.5–5 ac]." • p. 3
Swift 1995	• "Work to date indicates that localities smaller than about 20,000 square meters, or two hectares(about 5 acres), and a minimum of about 2000 overwintering fish are subject to natural and unnatural bottlenecks or complete extirpation of the species, at least under todays conditions." • "A watered surface area of about two hectares or 20,000 square meters (about 5 acres) seems to be about the minimum for maintenance of a population of at least two thousand fish during the low population levels in the winter or early spring. Areas smaller than this have histories of extinction, extirpation, or population reduction to very low levels. Many of the records for smaller localities, less than about half a hectare (1 acre), include one or a few large fish with no evidence of reproduction. Eighteen (17.5%) of todays localities fall into this category. These small localities are also within a kilometer (six tenths of a mile) or so of another locality. Thus the most stable or largest populations today are in localities of intermediate sizes, 2 to 40 or 50 hectares (5 to 125 acres) that have remained relatively unimpacted." • "The localities that are optimal also have a width that is one third or more the length of the lagoon with lateral marsh vegetation .Lagoons that are naturally or artificially narrower have much less or no marsh and are much more subject to winter scour. Even in typical lagoons, the lateral flooded marsh is seldom more than one-fourth

Source	Notes
	to one-third of the surface area of standing water." • p. 36 and 42
Pinnix and Gray 2005 (unpublished data)	• "The length of Gannon Slough from Site 3 to Site 10 was walked and tidewater gobies were observed throughout the length of the brackish portion of the slough. Gobies were seen in densities of approximately1-3 fish/m^2 from Site 3 to Site 9 and were seen near burrows. The habitat in this lower section (sites 2-9) is a layer of mud/sand approximately 6 inches deep over a sand/gravel substrate in a channel approximately 2-4 meters [7–13 ft] wide." • p. 1
Lafferty et al. 1999a	• "annual rates of extirpation were lower for large than small wetlands" (p. 1450). • "Stream flow, date, and wetland size explained only a portion (12%) of the variation in goby population dynamics" (p. 1452).
CONDUCTIVITY	
Irwin and Soltz 1984	• Occurrence of fish species and conductivity values for sample areas are summarized in Tables 1–4 of Irwin and Soltz 1984.
pH	
Pinnix and Gray 2005 (unpublished data)	• Occurrence of tidewater goby and pH values for sample areas are summarized in Tables 1and 2 of Pinnix and Gray 2005 (unpublished data).
Wang 1984 as cited in Chamberlain 2006	• "General habitat characteristics reported in the literature include:...pH of 6.8-9.5 (Wang 1984)." • p. 2

2 ADULT HABITAT

Table A-6. Velocity criteria for adult tidewater goby.

Velocity criteria				Source	Notes
Minimum	**Maximum**	**Average**	**Preferred/ optimal**		
					No information found

Table A-7. Depth criteria for adult tidewater goby.

Depth criteria				Source	Notes
Minimum	**Maximum**	**Average**	**Preferred/ optimal**		
17 cm (7 in)	131 cm (52 in)		50–85 cm (20–34 in)	Appendix B	Based on graphical analyses of mean monthly water depth and adult (>30 mm [1 in] TL) densities over a one year period, based on data from Carl Page, used in Tetra Tech Inc. 2000.
	4.6 m (15 ft)			Charlie Chamberlain, pers. comm.., 2006	Based on sampling in Big Lagoon with a small frame trawl towed by a small boat, May 2006.

Table A-8. Salinity criteria for adult tidewater goby.

Salinity criteria				Source	Notes
Minimum	**Maximum**	**Average**	**Preferred/ optimal**		
0 ppt	32 ppt		2–5 ppt	Appendix B	Based on graphical analyses of mean monthly salinity and adult (>30 mm [1 in] TL) densities over a one year period, based on data from Carl Page, used in Tetra Tech Inc. 2000.

Table A-9. Temperature criteria for adult tidewater goby.

Temperature criteria				Source	Notes
Minimum	**Maximum**	**Average**	**Preferred/ optimal**		
5.8°C (42°F)	24.0°C (75°F)		12–24°C (54–75°F)	Tetra Tech Inc. 2000	• "During the course of this study, temperatures within the sample sites ranged from 5.8 to 24 °C [42 to 75°F]. Tidewater goby were captured at nearly all temperatures within that range. Sites with temperatures between 12 and 24 °C [54 and 75°F] showed the highest densities, especially during spawning season." • Lake Earl and Lake Talawa • p. 8-12

Temperature criteria				Source	Notes
Minimum	**Maximum**	**Average**	**Preferred/ optimal**		
5.8°C (42°F)	24.0°C (75°F)		11–21°C (52–70°F)	Appendix B	Based on graphical analyses of mean monthly water temperature and adult (>30 mm [1 in] TL) densities over a one year period, based on data from Carl Page, used in Tetra Tech Inc. 2000.

Table A-10. Other potential factors influencing adult tidewater goby.

Source	Notes
HYDROPERIOD/TIDAL FLUCTUATIONS	
	No information found
VEGETATION ASSOCIATIONS (SPECIES, ETC)	
Worcester 1992 as cited in Swenson 1997	• “adults were more abundant in sparse to moderate amounts of submerged vegetation , while larval fish were more abundant in open, deeper (70 cm [28 in]) water” • p. 9
Appendix B	• Range from 10 to 100% vegetation cover for both juveniles and adults, with preference of >40%, based on graphical analyses of mean monthly vegetation cover and adult (>30 mm [1 in] TL) densities over a one year period, based on data from Carl Page, used in Tetra Tech Inc. 2000.
HABITAT TYPES	
McIvor and Odum 1988 and Rozas and Odum 1988 both as cited in Tetra Tech Inc. 2000	• "The microhabitat preference of larger gobies for vegetation may also reflect a need for cover." • p. 8-2
SUBSTRATE	
	No information found

3 REPRODUCTION/SPAWNING

Table A-11. Velocity criteria for spawning/burrows for tidewater goby.

Velocity criteria				Source	Notes
Minimum	**Maximum**	**Average**	**Preferred/ optimal**		
					No information found

Table A-12. Depth criteria for spawning/burrows for tidewater goby.

Depth criteria				Source	Notes
Minimum	**Maximum**	**Average**	**Preferred/ optimal**		
					No information found

Table A-13. Salinity criteria for spawning/burrows for tidewater goby.

Salinity criteria				Source	Notes
Minimum	**Maximum**	**Average**	**Preferred/ optimal**		
			8–15 ppt	Swenson 1997	• "Captive fish spawned regularly at 8–15 ppt" • p.13
2	27			Swenson 1997	• San Gregorio and Pescadero creeks • "Spawning occurred over a wide range of salinities" • p.13
0	27		8–15 ppt	Swenson 1999	• "Captive fish spawned regularly at 8-15 ppt" • "Spawning activity of wild fish was studied at San Gregorio and Pescadero…. Spawning occurred over a wide range of salinities (2–27 ppt)…" • p. 107
				Capelli 1997	• Spawning is most prevalent from spring to mid-summer when most California estuaries are naturally closed to the ocean and exhibit low-salinity brackish water conditions." • p. 6
				Swift et al. 1989; Swenson 1993a, 1993b and 1994; Robert N. Lea, pers. comm., 1991-1995 all as	• "Reproduction is heaviest from spring to mid-summer, late April or May to July, and can continue into November or December depending on the seasonal temperature and rainfall. Reproduction takes place between about 15 to 20 degrees Centigrade and at salinities of 0-25 parts per thousand." • p. 5

Salinity criteria				Source	Notes
Minimum	Maximum	Average	Preferred/ optimal		
				cited in Swift 1995	
5 ppt	25 ppt			Swift 1995	• "Tidewater gobies have carried out their breeding behavior in the laboratory for a t least three investigations. Several thousand were raised a t the Granite Canyon Hatchery facility of the California Department of Fish and Game, Carmel, California in the late1980s and early 1990s (R . Lea, personal communication, 1991-1995). Some of these tidewater gobies matured and spawned again. These gobies bred at salinities ranging from 5 t o 25 parts per thousand." • p. 6–7

Table 14. Temperature criteria for spawning/burrows for tidewater goby.

Temperature criteria				Source	Notes
Minimum	Maximum	Average	Preferred/ optimal		
			17–22°C (63–72°F)	Swenson 1997	• "Captive fish spawned regularly at 17–22°C [96–72°F]." • p.13
9°C (48°F)	25°C (77°F)			Swenson 1997	• San Gregorio and Pescadero creeks • "Spawning occurred over a wide range of temperatures" • p.13
9°C (48°F)	25°C (77°F)		17–22°C (63–72°F)	Swenson 1999	• “Captive fish spawned regularly at 8–15 ppt and 17–22°C [63–72°F].” • “Spawning activity of wild fish was studied at San Gregorio and Pescadero…. Spawning occurred over a wide range of salinities (2–27 ppt) and temperatures (9–25°C [48–77°F]).” • p. 107
				Swenson 1997	• San Gregorio and Pescadero creeks • The author contributed spawning lulls to colder temperatures or hydrological disruptions in the winter, and high temperatures for mid-summer months ("although spawning usually resumed in August and Septembers when temperatures were high") • p. 14
				Tetra Tech Inc. 2000	• "High temperatures can inhibit reproduction." • p. 8-3

Temperature criteria				Source	Notes
Minimum	**Maximum**	**Average**	**Preferred/ optimal**		
5.8°C (42°F)	24.0°C (75°F)		12–24°C (54–75°F)	Tetra Tech Inc. 2000	• "During the course of this study, temperatures within the sample sites ranged from 5.8 to 24°C [42 to 75°F]. Tidewater goby were captured at nearly all temperatures within that range. Sites with temperatures between 12 and 24 °C [54 and 75°F] showed the highest densities, especially during spawning season." • Lake Earl and Lake Talawa • p. 8-12
				Swift et al. 1989, Swenson 1995, and Swenson 1997 all as cited in Capelli et al. 1997	• "Spawning is generally halted by the onset of colder weather and the first winter rains which result in breaching of the sand and cobble berm and the temporary conversion of the estuary to fresh water. However, spawning activity may persist into early fall and winter if water temperatures remain warm, and freshwater inflow is not increased sufficiently to breach the sand and cobble berm at the mouth of the estuary." • p. 5
				Swift et al. 1989; Swenson 1993a, 1993b and 1994; Robert N. Lea, pers. comm., 1991-1995 all as cited in Swift 1995	• "Reproduction is heaviest from spring to mid-summer, late April or May to July, and can continue into November or December depending on the seasonal temperature and rainfall. Reproduction takes place between about 15 to 20 degrees Centigrade [59–68°F] and at salinities of 0-25 parts per thousand." • p. 5
				Swift 1995	• "Typically winter rains and cold weather interrupt spawning, but in some drought years reproduction may occur all year." • p. 6
				Swift et al. 1989	• "At Aliso Creek, breeding commenced in late April1974 in the upper end of the lagoon. Water temperature was 18-19°C [64–66°F] and salinity was low, but not recorded." • p. 9
				Swift et al. 1989	• "The potential for year-round spawning exists but probably is seldom, if ever, realized because of low temperatures and disruption of lagoons by winter rains." • p. 14

Table A-15. Tidewater goby spawning burrow size and characteristics.

Burrow area	Burrow dimensions	Burrow depth	Source	Notes
		24–30 cm (9–12 in)	Swift et al. 1989	• "About 30 burrows were found on 28 April 1974, concentrated on a sand shoal 3 m [10 ft] long, 0.5 m [2 ft] wide, and in an 11-m [36-ft] linear series parallel to one steep, north-facing shoreline. The shoreline entered the water at about a 45" angle. The burrow entrances, as those on the sandbar, all were 24–30 cm [9–12 in] deep. At Bean Hollow Lagoon, the burrows found were restricted to a 4-m^2 [43-ft^2] area of sandy mud. The entrances of the more or less vertical burrows at Aliso Creek were surrounded by a rounded area of cream or yellowish sand (42-160 mm [2–6 in] diameter ,n = 26, mean = 72.3) that contrasted with the darker adjacent undisturbed sand. Distances between the edges of the clear sandy areas ranged from 50 to 550 mm [2 to 22 in] (n = 22, mean = 143.5) • p. 9

Table A-16. Substrate sizes/types of tidewater goby burrows.

Substrate size				Source	Notes
Minimum	Maximum	Average	Preferred/ optimal		
			"sand"	Swenson, unpublished data as cited in Swenson 1997	• "When offered two different sediments, they preferred to spawn in sand rather than mud." • p. 13
			"sand"	Swift et al. 1989 as cited in Tetra Tech Inc. 2000	• "...prefer to burrow in sandy substrate found in lagoons rather than in the mud of marshes." • p. 8-3
		0.5 mm (0.02 in)		Swift 1995	• "Males begin digging breeding burrows in relatively unconsolidated, clean, coarse sand (averaging 0.5 millimeters [0.02 in], in April or May after lagoons close to the ocean." • p. 4–5
			"coarse sand"	Swift et al. 1989 and Swenson 1994 both as cited in Swift 1995	• "Burrows are usually in coarse sand in the field (Swift et al. 1989;Swenson 1994). Swenson (1994) has shown that tidewater gobies prefer this substrate in the laboratory also (Swenson 1994)." • p. 4–5
				Swenson 1995 as cited in Swenson 1996	• "The male tidewater goby digs a simple, vertical burrow in sand or mud for spawning." • p. 3
				Capelli 1997	• "Before spawning, males excavate breeding burrows in clean, unconsolidated sand." • p. 6

Substrate size				Source	Notes
Minimum	Maximum	Average	Preferred/ optimal		
				Swift et al. 1989	• "About 30 burrows were found on 28 April 1974, concentrated on a sand shoal 3 m long, 0.5 m wide, and in an 11-m linear series parallel to one steep, north-facing shoreline. The shoreline entered the water at about a 45° angle. The burrow entrances, as those on the sandbar, all were 24–30 cm deep. At Bean Hollow Lagoon, the burrows found were restricted to a 4-m^2 area of sandy mud. The entrances of the more or less vertical burrows at Aliso Creek were surrounded by a rounded area of cream or yellowish sand (42-160 mm diameter ,n = 26, x = 72.3) that contrasted with the darker adjacent undisturbed sand. Distances between the edges of the clear sandy areas ranged from 50 to 550 mm (n = 22, x = 143.5) • p. 9

Table A-17. Other characteristics of spawning sites chosen by tidewater goby.

Source	Notes
	HYDROPERIOD/TIDAL FLUCTUATIONS
Swift et al. 1989, Swenson 1995, and Swenson 1997 all as cited in Capelli et al. 1997	• "Spawning is generally halted by the onset of colder weather and the first winter rains which result in breaching of the sand and cobble berm and the temporary conversion of the estuary to fresh water. However, spawning activity may persist into early fall and winter if water temperatures remain warm, and freshwater inflow is not increased sufficiently to breach the sand and cobble berm at the mouth of the estuary." • p. 5
	VEGETATION ASSOCIATIONS (SPECIES, ETC)
Tetra Tech 2000	• In most of Lake Earl and over half of Lake Talawa, spawning habitat was limited to a few areas protected from wind-driven surges. This was further reduced by thick stands of bulrush (*Scirpus* spp.) which displaced key shallow water marginal habitat. • p. 8-10
Tetra Tech Inc. 2000	• "...the results of this study showed no discernable preference. However, it should be noted that the sample containing the highest density of goby (312 individuals, 101 of which were gravid females) observed was taken in a site that was 100% vegetated." • Lake Earl and Lake Talawa • p. 8-12
	HABITAT TYPES
	No information found
	SUBSTRATE
	No information found

4 JUVENILE HABITAT

Table A-18. Velocity criteria for juvenile tidewater goby.

Velocity criteria				Source	Notes
Minimum	**Maximum**	**Average**	**Preferred/ optimal**		
					No information found

Table A-19. Depth criteria for juvenile tidewater goby.

Depth criteria				Source	Notes
Minimum	**Maximum**	**Average**	**Preferred/ optimal**		
				Worcester 1992 as cited in Swenson 1997	• "larval fish were more abundant in open, deeper (70 cm [28 in]) water" • p. 9
14 cm (6 in)	132 cm (52 in)		50–80 cm (20–32 in)	Appendix B	• Based on graphical analyses of mean monthly water depth and juvenile (<30 mm [1 in] TL) densities over a one year period, based on data from Carl Page, used in Tetra Tech Inc. 2000.

Table A-20. Salinity criteria for juvenile tidewater goby.

Salinity criteria				Source	Notes
Minimum	**Maximum**	**Average**	**Preferred/ optimal**		
0 ppt	32 ppt		2–5 ppt	Appendix B	Based on graphical analyses of mean monthly salinity and juvenile (<30 mm [1 in] TL) densities over a one year period, based on data from Carl Page, used in Tetra Tech Inc. 2000.

Table A-21. Temperature criteria for juvenile tidewater goby.

Temperature criteria				Source	Notes
Minimum	**Maximum**	**Average**	**Preferred/ optimal**		
5.8°C (42°F)	24.0°C (75°F)		11–21°C (52–70°F)	Appendix B	Based on graphical analyses of mean monthly water temperature and juvenile (<30 mm [1 in] TL) densities over a one year period, based on data from Carl Page, used in Tetra Tech Inc. 2000.

Table A-22. Other characteristics summer (late summer/fall) rearing habitat for tidewater goby.

Source	Notes
HYDROPERIOD/TIDAL FLUCTUATIONS	
Tetra Tech 2000	• "Frequent breaching events could jeopardize food supplies for tidewater goby and other fish species in the lagoon. The longer the lagoon remains open, the more the ecosystem shifts in favor of marine organisms, which would detrimentally affect the post-larval goby's ability to forage on freshwater planktonic prey and invertebrates."
Chamberlain 2006	• "In their larval stage, tidewater gobies are pelagic and are therefore more susceptible to entrainment in waters ebbing out of a habitat than would the later benthic-oriented life histories of the species. Large lagoons, in addition to often having a closed sandbar for most of the year, exhibit a low turnover of water with each tide when they're open by virtue of their enormity relative to their mouths, and provide vast areas of refuge from entrainment in ebbing waters. Marshes with only partial or intermittent connection to tidal influence can also provide critical refuge from entrainment. Sandbar formation at many lagoons and estuaries frequently severs connection with tidal influences, often for many months." • "And after hatch, recruitment of larvae to the benthic life history requires subsequent refuge from entrainment out of the water body for a period lasting maybe as long as a couple weeks or more." • "Waters that occasionally connect with, but are periodically discontinuous from the tidal environment provide refuge for larval gobies to make the life history transition to benthic juveniles. Though often found throughout estuaries, tidewater goby have been described to have a higher affinity for the upper end of bays and large estuaries (Swift et al. 1989; Capelli 1997). It's reasonable to suppose that individuals (especially larvae) at upper ends of these water bodies are less exposed to entrainment out of the system." • p. 43, July-Oct. 1996, N. California
VEGETATION ASSOCIATIONS (SPECIES, ETC)	
Worcester 1992 as cited in Swenson 1997	• "adults were more abundant in sparse to moderate amounts of submerged vegetation , while larval fish were more abundant in open, deeper (70 cm [28 in]) water" • p. 9
Appendix B	• Range from 10 to 100% vegetation cover for both juveniles and adults, with preference of >40%, based on graphical analyses of mean monthly vegetation cover and adult (>30 mm [1 in] TL) densities over a one year period, based on data from Carl Page, used in Tetra Tech Inc. 2000.
HABITAT TYPES	
Eldridge and Bryan 1972 as cited in Swift 1995	• "The larvae reported by Eldridge and Bryan (1972) were within the estuarine area of Humboldt Bay." • p. 4
SUBSTRATE	
	No information found

5 LITERATURE CITED

Ballard, E. D., and C. C. Swift. 1996. Tidewater goby (*Eucyclogobius newberryi*). Draft recovery plan. U.S. Fish and Wildlife Service, Region 1.

Bell, M. A. 1979. Low-plate morph of the three spine stickleback breeding in salt water. Copeia 1979: 529-533.

Capelli, M. H. 1997. Tidewater goby (*Eucyclogobius newberryi*) management in California estuaries. Proceedings from California and the World Ocean Conference, March 24-27, 1997, San Diego, California

Eldridge, M. B., and C. F. Bryan. 1972. Larval fish survey at Humboldt Bay, California. Technical report, SSRF-665. National Marine Fisheries Service.

Chamberlain, C. D. 2006. Environmental variables of northern California lagoons and estuaries and the distribution of tidewater goby (*Eucyclogobius newberryi*). Draft technical report No. XX. U. S. Fish and Wildlife Service, Arcata Fish and Wildlife Office, Arcata, California.

Fierstine, H. L., K. F. Kline, and G. R. Garman. 1973. Fishes collected in Morro Bay, California between January, 1968 and December, 1970. California Fish and Game 59: 73-88.

Hubbs, C. 1947. Mixture of marine and fresh-water fishes in the lower Salinas River, California. Copeia 1947: 147-149.

Irwin, J. F., and D. L. Soltz. 1984. The natural history of the tidewater goby, *Eucyclogobious newberryi*, in the San Antonio and Shuman Creek systems, Santa Barabara county, California. Contract Order No. 11310-0215-2 US Fish and Wildlife Service, Sacramento Endangered Speices Office, Sacramento, California.

Josselyn, M., J. B. Zedler, and T. Griswold. 1990. Wetland mitigation along the Pacific coast of the United States. J. A. Kusler and M. E. Kentula, editors. Wetland creation and restoration: the status of the science. Island Press.

Lafferty, K. D., C. C. Swift, and R. F. Ambrose. 1999a. Extirpation and recolonization in a metapopulation of an endangered fish, the tidewater goby. Conservation Biology 13: 1447-1453.

Lafferty, K. D., C. C. Swift, and R. F. Ambrose. 1999b. Postflood persistence and recolonization of endangered tidewater goby populations. North American Journal of Fisheries Management 19: 618-622.

McIvor, C. C., and W. E. Odum. 1988. Food, predation risk, and microhabitat selection in a marsh fish assemblage. Ecology 69.

Moyle, P. B. 2002. Inland fishes of California. Revised edition. University of California Press, Berkeley.

Pinnix, W., and G. Gray. 2005. Report of tidewater goby survey conducted at Gannon Slough, Arcata, California. Unpublished data.

Rozas, L. P., and W. E. Odum. 1988. Occupation of submerged aquatic vegetation by fishes: testing the roles of food and refuge. Oecologia (Berl.) 77: 101-106.

Shapovalov, L., and A. C. Taft. 1954. The life histories of the steelhead rainbow trout (*Salmo gairdneri gairdneri*) and silver salmon (*Oncorhynchus kisutch*) with special reference to Waddell Creek, California, and recommendations regarding their management. Fish Bulletin 98. California Department of Fish and Game.

Smith, J. J. 1990. The effects of sandbar formation and inflows on aquatic habitat and fish utilization in Pescadero, San Gregorio, Waddell and Pomponio creek estuary/ lagoon systems, 1985-1989. Department of Biology, San Jose State University.

Swenson, R. O. 1993a. The ecology and reproductive biology of the tidewater goby (*Eucyclogobius newberryi*). The Western Proceedings, 1993 annual conference Western Association of Fish and Wildlife Agencies, Western Division. American Fisheries Society, July 22-29, Sacramento, California.

Swenson, R. O. 1993b. Marshes build better gobies: population dynamics and reproduction in an estuarine fish, *Eucyclogobius newberryi*. American Zoologist 33: 441 (Abstract).

Swenson, R. O. 1994. A survey of the tidewater goby (*Eucyclogobius newberryi*) and a recent invader, the shimofuri gobi (*Tridentiger bifasciatus*). Presented, Cal-Neva Chapter American Fisheries Society, Napa, California, 3 February 1995.

Swenson, R. O. 1995. The reproductive behavior and ecology of the tidewater goby *Eucyclogobius newberryi* (Pices: Gobiidae). Ph.D. dissertation. University of California, Berkeley.

Swenson, R. O. 1996. 1995 annual report of tidewater goby study activities. Trihey & Associates, Inc., Concord, California.

Swenson, R. O. 1997. The ecology, behavior, and conservation of the tidewater goby, *Eucyclogobius newberryi.* Museum of Vertebrate Zoology, Department of Integrative Biology, University of California, Berkeley, California.

Swenson, R. O. 1999. The ecology, behavior, and conservation of the tidewater goby, *Eucyclogobius newberryi*. Environmental Biology of Fishes 55: 99-114.

Swenson, R. O., and A. T. McCray. 1996. Feeding ecology of the tidewater goby. Transaction of the American Fisheries Society 125: 956-970.

Swift, C. C. 1995. Draft recovery plan for the tidewater goby, *Eucyclogobius newberryi.* Prepared for Region 1, U. S. Fish and Wildlife Service, Portland, Oregon.

Swift, C. C., J. L. Nelson, C. Maslow, and T. Stein. 1989. Biology and distribution of the tidewater goby, *Eucyclogobius newberryi* (Pisces: Gobiidae) of California. Contribution Science. Natural History Museum of Los Angeles County, Los Angeles, California 404: 19 pp.

Swift, C. C., J. N. Baskin, and T. R. Haglund. 1994. Thje status and distribution of the tidewater goby, *Eucyclogobius newberryi* (Pisces, Gobiidae), on MCB Camp Pendleton, California. Final report. Prepared by San Marino Enviromental Associates, San Marino, California for Environmental and Natural Resources Office, Camp Pendleton, California.

Tetra Tech, Inc. 2000. Final report intensive habitat survey for Lake Earl and Lake Talawa, Del Norte County, California. Prepared by Tetra Tech, Inc., San Francisco, California for US Army Corps of Engineers, San Francisco District, San Francisco, California.

Trihey and Associates, Inc. 1996. Monitoring of the tidewater goby population in Rodeo lagoon, Golden Gate National Recreation Area. Prepared for National Park Service, Golden Gate National Recreation Area, San Francisco, California.

USFWS (U. S. Fish and Wildlife Service). 1994. Endangered and threatened wildlife and plants; determination of endangered status for the tidewater goby. Federal Register 59: 5,494-5,498.

USFWS (U. S. Fish and Wildlife Service). 1999. Endangered and threatened wildlife and plants; proposed rule to remove the northern populations of the tidewater goby from the list of endangered and threatened wildlife. Federal Register 64: 33,816-33,825.

USFWS (U. S. Fish and Wildlife Service). 2000. Endangered and threatened wildlife and plants: designation of critical habitat for the tidewater goby. Federal Register 65 (24) 69,693-69,717

USFWS (U. S. Fish and Wildlife Service). 2002. Endangered and threatened wildlife and plants; withdrawal of proposed rule to remove the northern populations of the tidewater goby from the list of endangered and threatened wildlife. Federal Register 67: 67,803-67,818.

USFWS (U. S. Fish and Wildlife Service). 2005. Recovery plan for the tidewater goby (*Eucyclogobius newberryi*). U. S. Fish and Wildlife Services, Portland, Oregon.

Videler, J. J. 1993. Fish swimming. Chapman and Hall, New York, New York.

Wang, J. C. S. 1984. On the ecological status of the tidewater goby, *Eucyclogobius newberryi* (Girard), in a lagoon and lake of the Golden Gate National Recreation Area, California. Technical Report No. 15. Cooperative National Park Resources Studies Unit, University of California, Davis, California.

Wang, J. C. S., and T. P. Keegan. 1988. Assessment of an oil spill on selected fishes in Rodeo Lagoon and Muir Beach. Technical report No. 29. Cooperative National Park Resources Studies Unite, University of California, Davis, California.

Worcester, K. R. 1992. Habitat utilization in a central California coastal lagoon by the tidewater goby (*Eucyclogobius newberryi*). Master's thesis. California Polytechnic State University, San Luis Obispo.

Worcester, K. R., and R. N. Lea. 1996. Observation on tidewater goby habitat utilization and laboratory maintenance during the California drought. Unpublished abstract from Symposium on tidewater goby, Southern California Academy of Sciences Annual Meeting, May 3-4, 1996.

Appendix B

Graphical Analysis of Tidewater Goby Data from Collections in Lake Earl, September 1998—August 1999

Figures

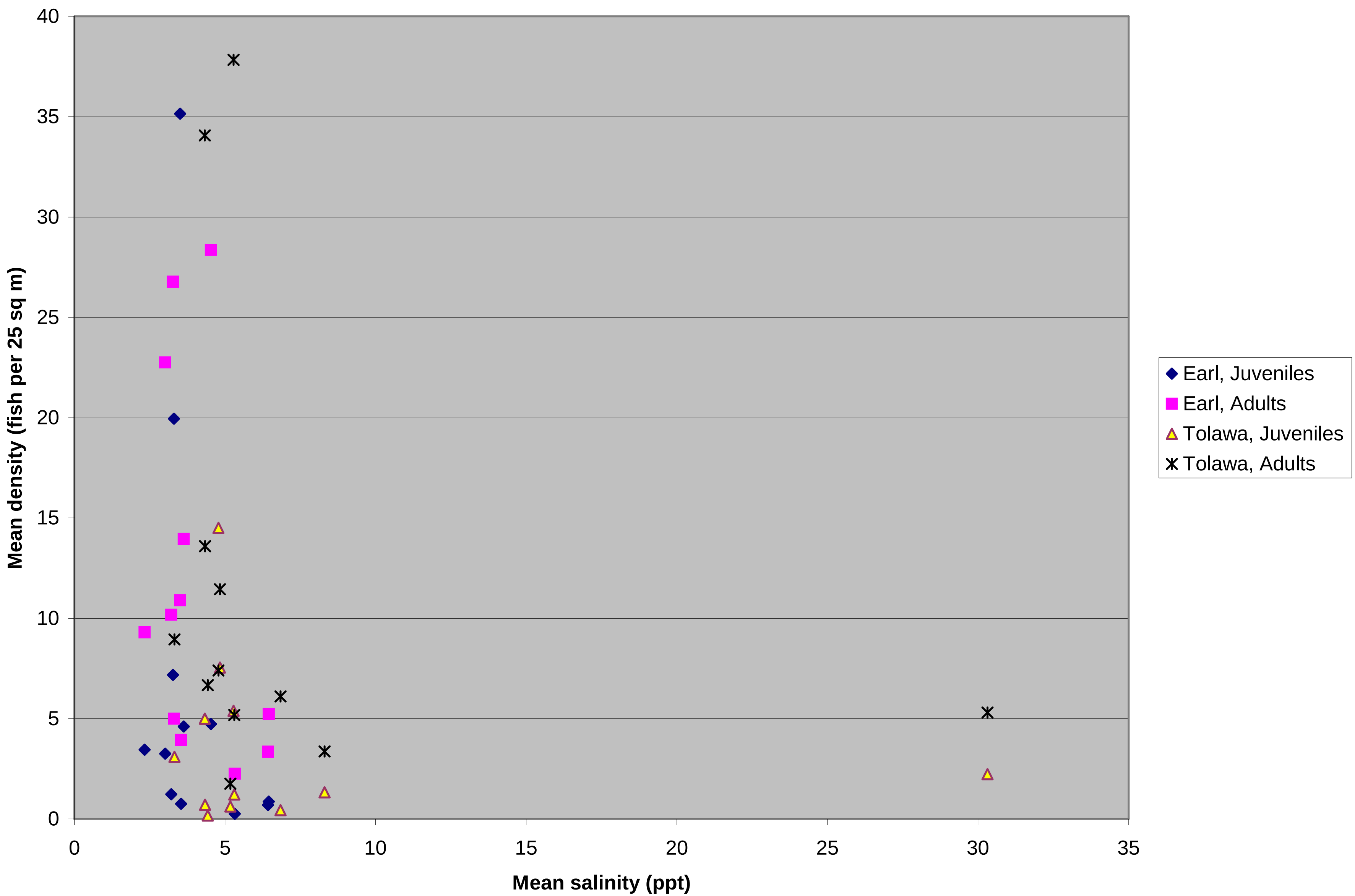

Figure 1. Mean tidewater goby density (per 25 sq m) versus salinity (ppt), by size class, September 1998 to August 1999, Lake Earl system.

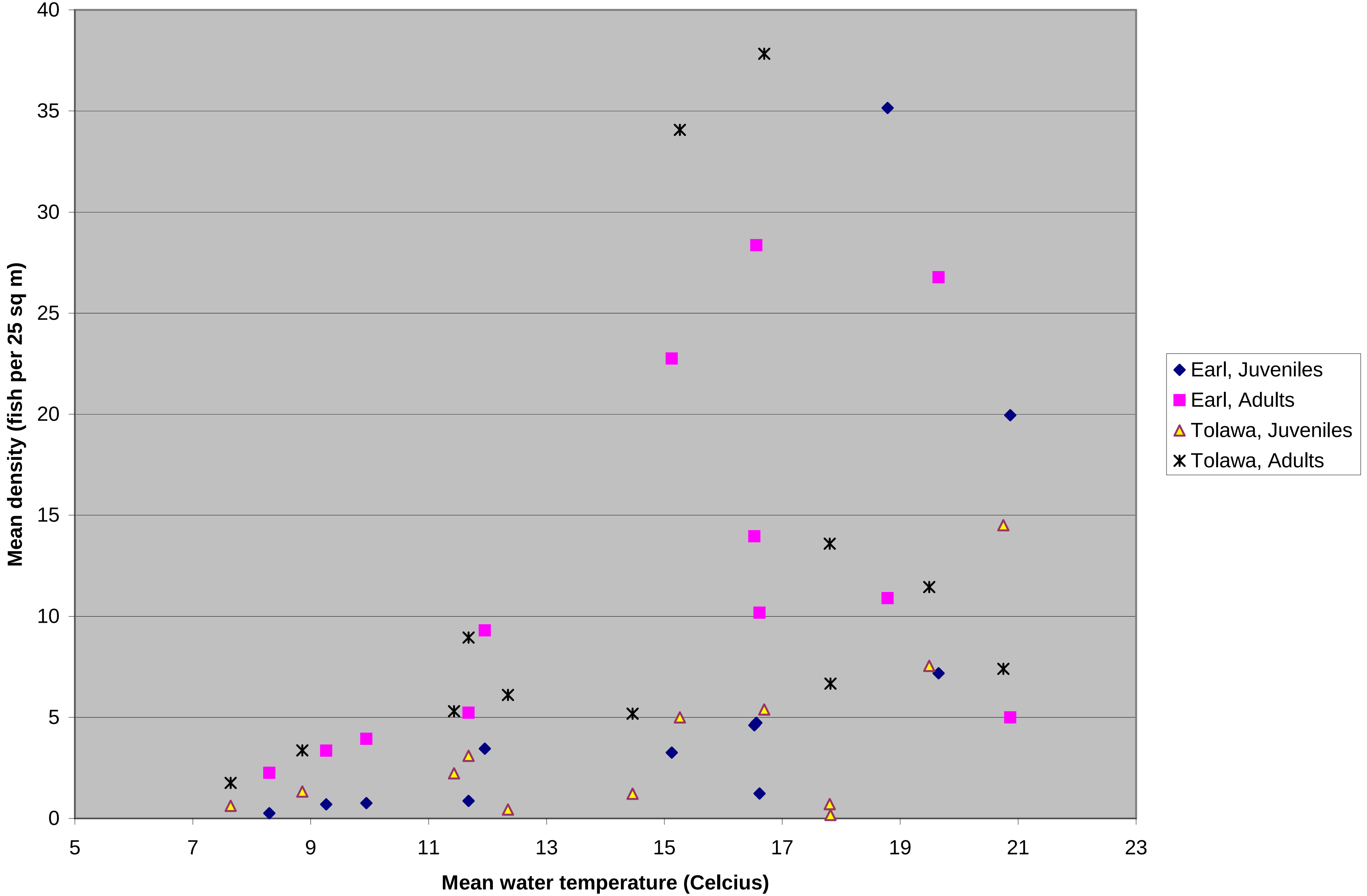

Figure 2. Mean tidewater goby density (per 25 sq m) versus temperature (Celcius), by size class, September 1998 to August 1999, Lake Earl system.

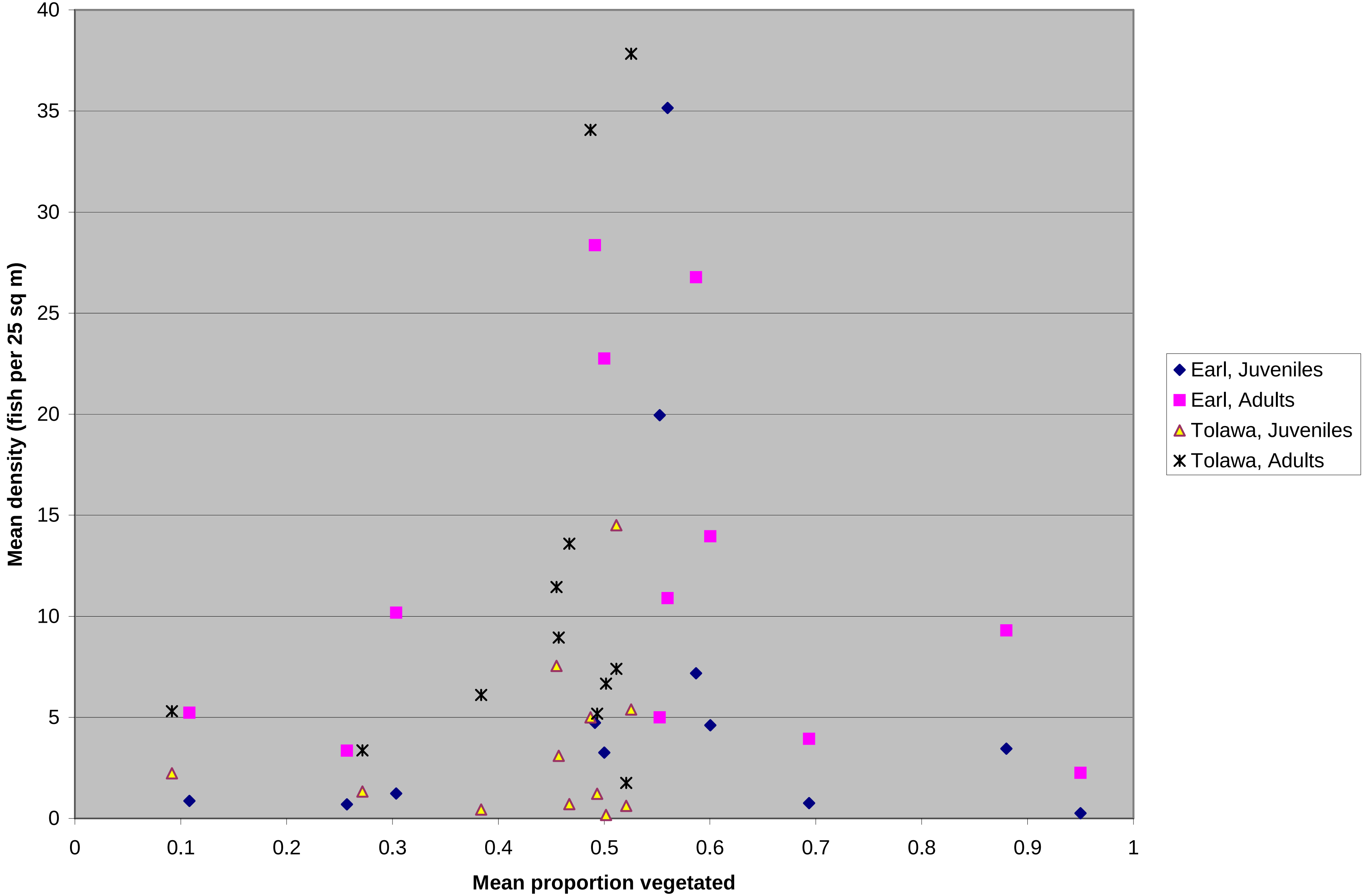

Figure 3. Mean tidewater goby density (per 25 sq m) versus mean proportion vegetated, by size class, September 1998 to August 1999, Lake Earl system.

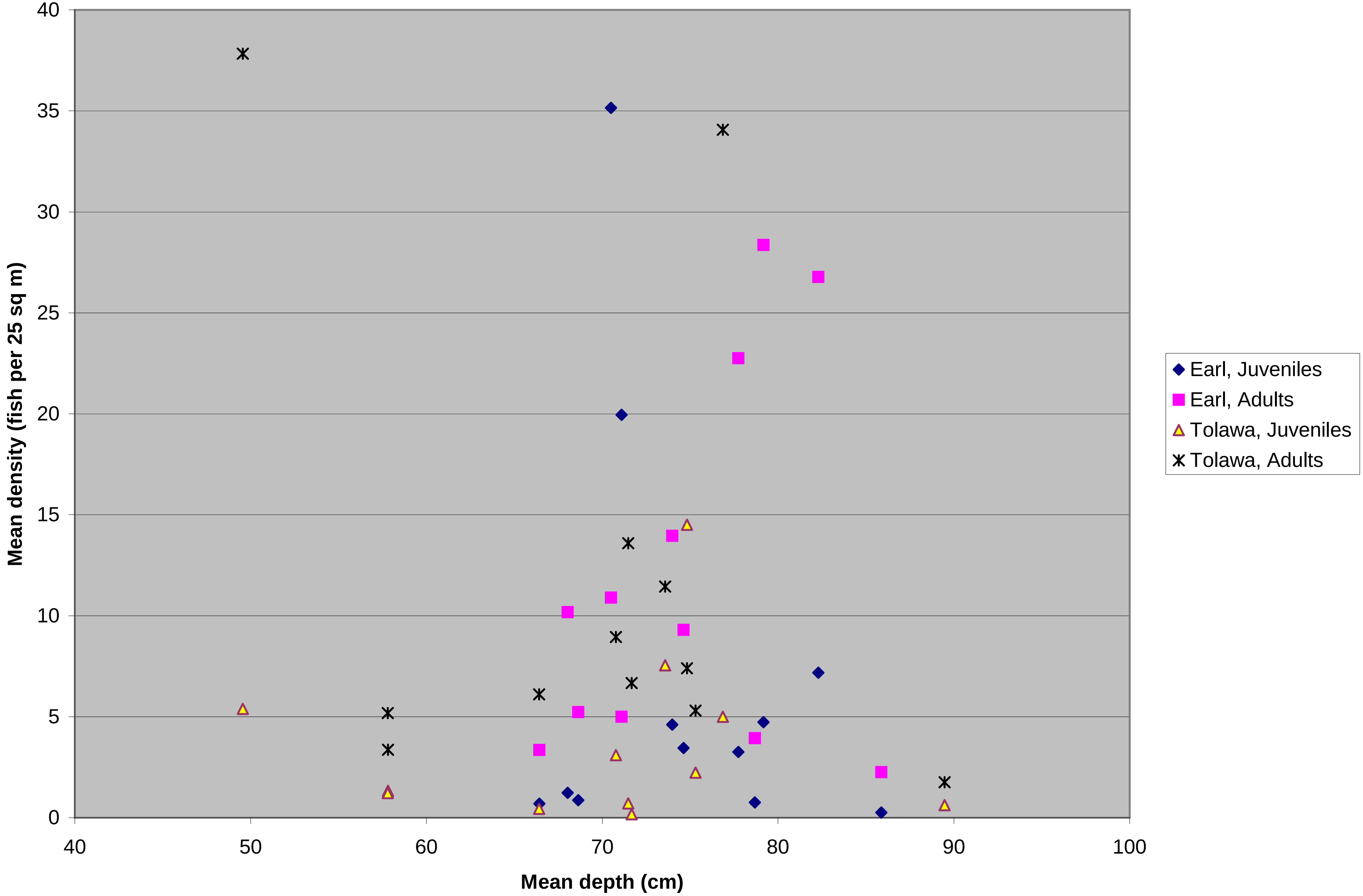

Figure 4. Mean tidewater goby density (per 25 sq m) versus mean depth (cm) by size class, September 1998 to August 1999, Lake Earl system.