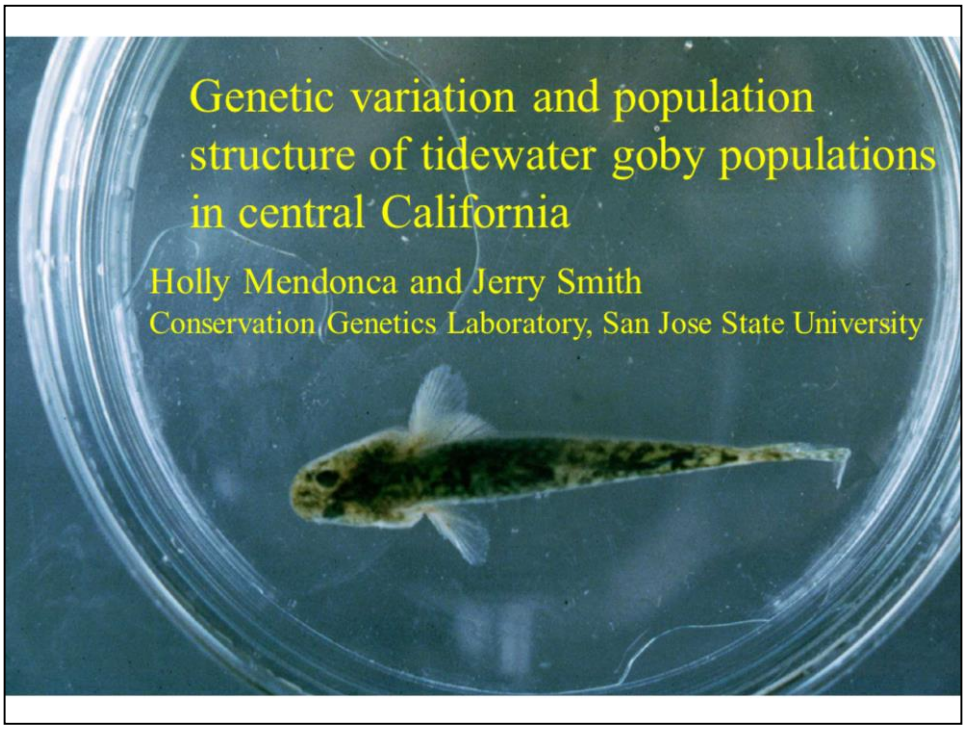
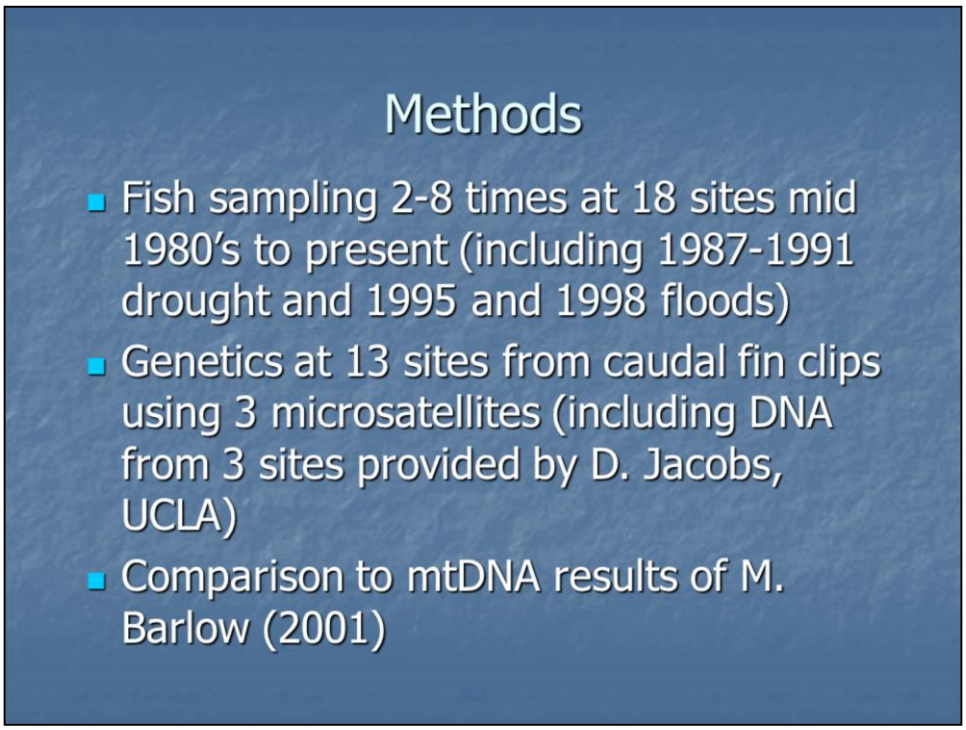
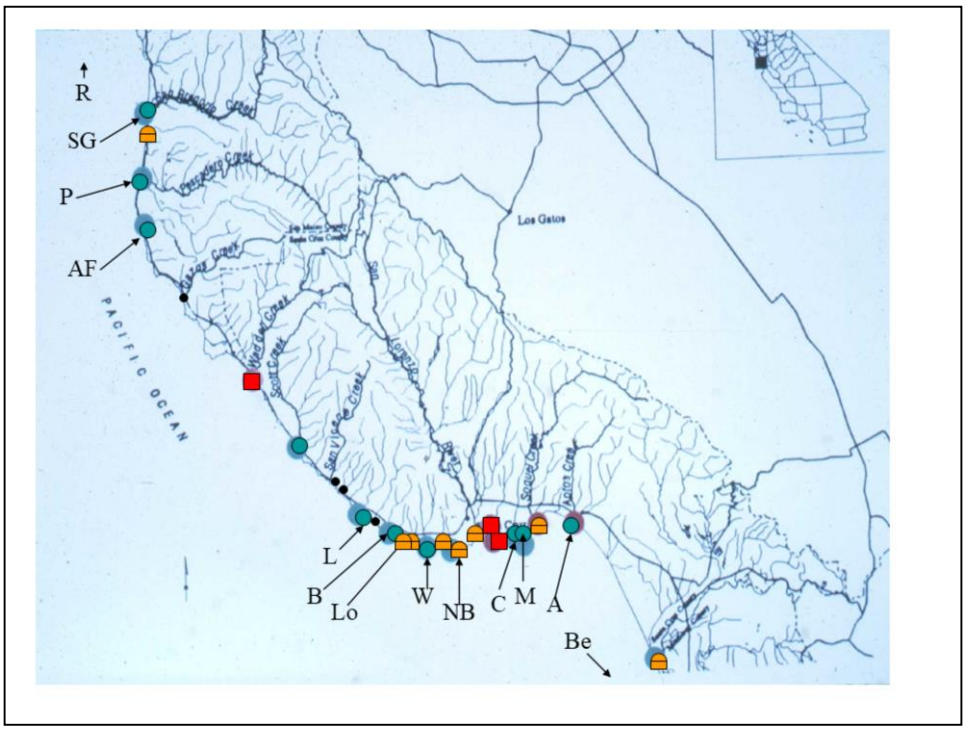


Presentation at the Cal-Neva Chapter meeting of the American Fisheries Society (2006). Text added and updated to reflect conditions in 2017.



Population structure structure and ecology inferred from sampling of 18 sites in San Mateo and Santa Cruz counties 2-8 times from the mid 1980's through 2005. This included sampling associated with the 1987-1991 drought (which dried or nearly dried several sites) and following 1995 and 1998 floods (which can potentially eliminate gobies from sites without winter flood refuges. Extant sites survived both challenges.

Genetics using 3 microsatellites developed by Holly Mendonca as part of her thesis work. Michelle Barlow's thesis (2001, UCLA) used mtDNA, which had additional haplotype diversity.



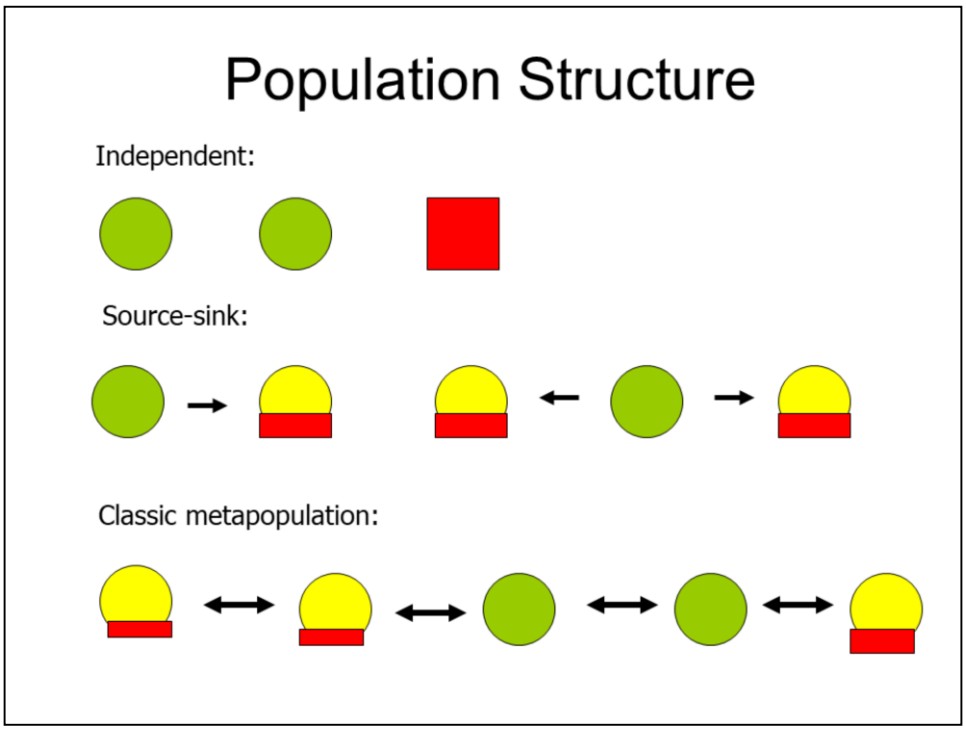
For this map of San Mateo and Santa Cruz counties, sites in green circles are sites that apparently consistently maintained tidewater gobies through droughts and floods (including Laguna Creek (L) and Aptos Creek (A) which were thought to have lost populations, but for which genetic information indicates unique mtDNA haplotypes that persisted).

Sites with red squares lost their populations due to flood or drought impact or due to habitat alteration.

Sites with orange rectangles and semicircles are populations subject to periodic loss of populations and recovery from reestablishment by adjacent populations.

Small black circles are locations where gobies may have been historically present (but with no record) which are not occupied (or in some cases no longer suitable)

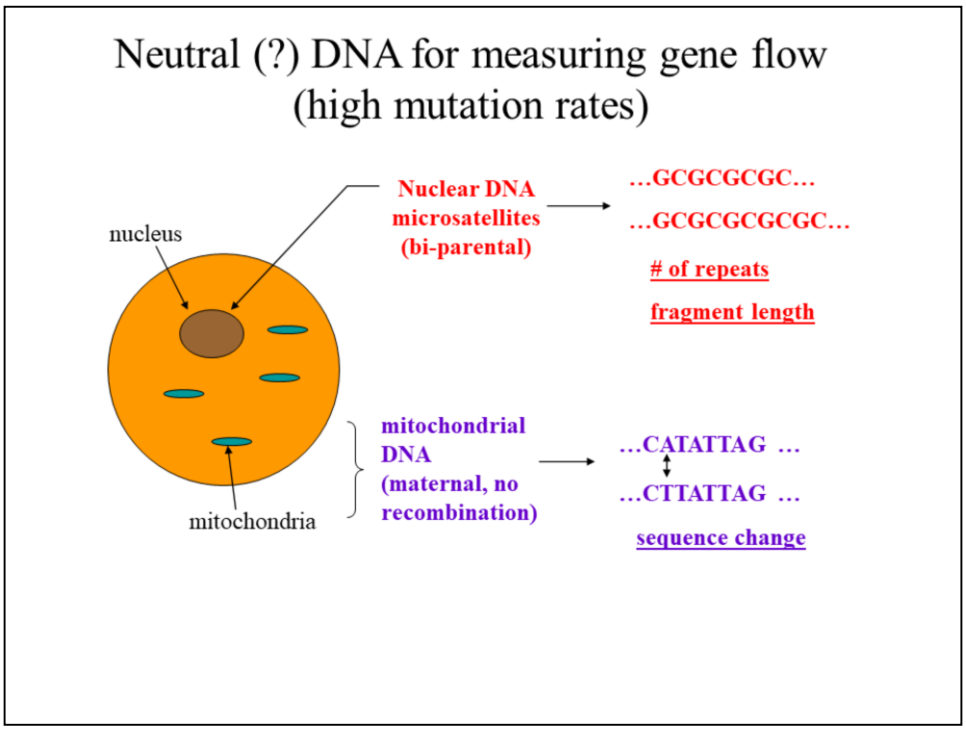
There is a wide variety of spacing between adjacent populations, so for many widely spaced populations there is little or no probability of goby reestablishment.



Within the 2 counties there are apparent examples of several types of population structure. Where spacing is wide, the likely structure is that of independent populations with no recent demographic or genetic interaction (top).

At other locations movement from stable populations periodically reestablish populations that "wink out" because of drought or flood impacts. The movement is likely in one direction because of currents, numbers etc. The survival of the metapopulation is not enhanced or only marginally enhanced and source population's independent survival is crucial.

There may also be classic metapopulations, where movement of individuals and genes moves in both directions; reciprocal rescue periodically occurs and overall survival of the metapopulation is enhanced. These populations are usually closely adjacent.



We used microsatellites, which are tandem repeats of DNA from the nucleus. Although inherited from both parents, the DNA is presumably neutral and doesn't code for functional traits. Microsatellites mutate quickly by adding and substracting repeat segments (stutter).

Michelle Barlow used mitochondrial DNA inherited from the mother. Mutations are changes in the sequence. As for microsatellites, the changes are presumably neutral.

Allelic Frequencies

Locus/ alleles (bp)	Rodeo	SanGreg	Pesca	Frijoles	Laguna	Baldwin	Lombar
						1990/2000	
Ene 2							
142	3				58	31/32	29
144							
148	82	100	100	100	42	53/53	59
152	15					17/15	12
Ene 3							
120	67	8	20	10	29	36/27	40
126						14/18	6
130	33	92	80	90	71	50/55	55
Ene 4							
214			24				
216	57				50	0/4	12
218	43	100	76	100	52	100/96	88
220							
Ho	42	4	24	7	54	32/45	37

Sample of data for three microsatellites at seven sites. The allelles in column one are the number of base pairs in the sequence (fragment length) . The remainder of the table consists of allele frequencies at the sites.

Allelic Frequencies

Locus/ alleles (bp)	Rodeo	SanGreg	Pesca	Frijoles	Laguna	Baldwin	Lombar
						1990/2000	
Ene 2							
142	3				58	31/32	29
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152	15					17/15	12
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120	67	8	20	10	29	36/27	40
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130	33	92	80	90	71	50/55	55
Ene 4							
214			24				
216	57				50	0/4	12
218	43	100	76	100	52	100/96	88
220							
Ho	42	4	24	7	54	32/45	37

Repeat sampling at Baldwin Creek (in 1990 and 2000) showed stable allele frequencies at the site.

Allelic Frequencies

Locus/ alleles (bp)	Rodeo	SanGreg	Pesca	Frijoles	Laguna	Baldwin	Lombar
						1990/2000	
Ene 2							
142	3				58	31/32	29
144							
148	82	100	100	100	42	53/53	59
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214			24				
216	57				50	0/4	12
218	43	100	76	100	52	100/96	88
220							
Ho	42	4	24	7	54	32/45	37

There were few alleles, so differences between sites were primarily in the frequency of shared alleles. However, at Pescadero Lagoon a unique allele of 214 base pairs at the Ene 4 locus was reasonably common. Its absence at the two adjacent sites (San Gregorio and Arroyo de las Frijoles lagoons indicates a probable lack of gene floww (or rescue) between the populations.

Allelic Frequencies

Locus/ alleles (bp)	Rodeo	SanGreg	Pesca	Frijoles	Laguna	Baldwin	Lombar
						1990/2000	
Ene 2							
142	3				58	31/32	29
144							
148	82	100	100	100	42	53/53	59
152	15					17/15	12
Ene 3							
120	67	8	20	10	29	36/27	40
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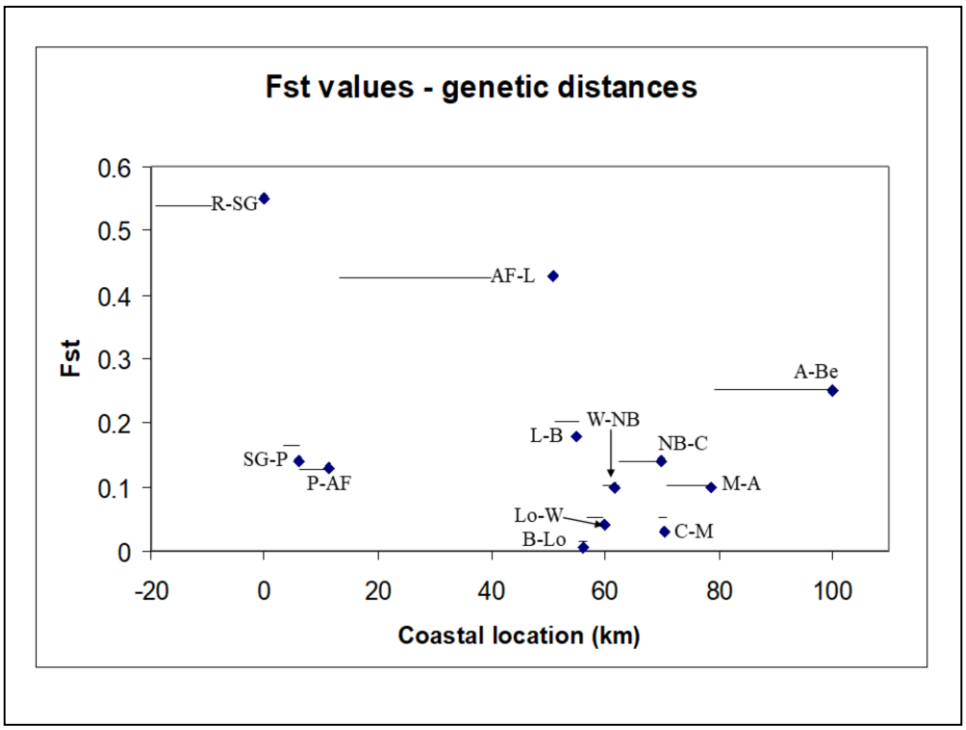
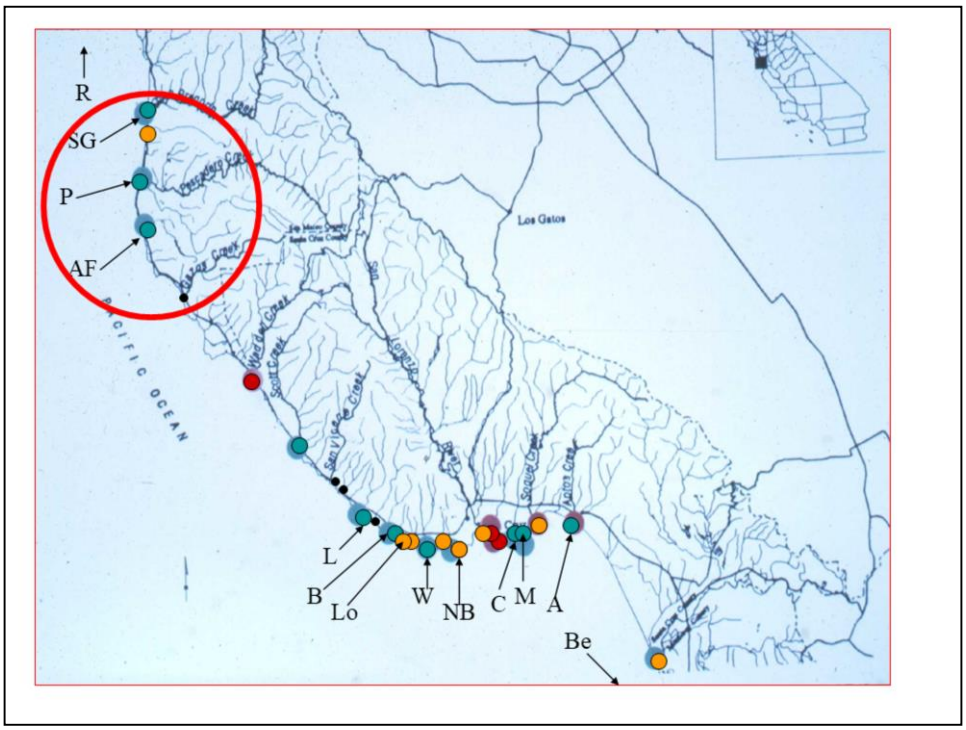
130	33	92	80	90	71	50/55	55
Ene 4							
214			24				
216	57				50	0/4	12
218	43	100	76	100	52	100/96	88
220							
Ho	42	4	24	7	54	32/45	37

Other sites differed in frequencies of shared alleles suggesting low levels of recent gene flow.



A measure of genetic distance between pairs of populations “FST” showed a strong isolation by distance pattern. Adjacent populations separated by more than 5 km had FST values greater than 0.1. More closely adjacent populations showed little genetic difference.



Population ecology and structure patterns analyzed in groups show different patterns. The northern cluster of San Gregorio, Pomponio, Pescadero and Arroyo de las Frijoles appears to be largely independent populations, but with some evidence of movement.

Pomponio Creek Lagoon lacked gobies in the 1980's, possibly due to loss in the severe storms of 1982 and 1983; flood refuge habitat is limited. However, tidewater gobies were present in 2011, apparently representing colonization from San Gregorio Creek, to the north. The coastal terrain is rocky and currents move almost exclusively north to south. Pomponio Creek may be a sink population, but can also act as a stepping stone.

Because of the current pattern, San Gregorio, at the north end of the cluster probably rarely, if ever, receives gobies from the other populations. Although a usually large population, it is nearly genetically fixed for the 3 microsatellites; it has apparently gone through a severe population bottleneck (flood, drought?).

The lack of the unique Pescadero Creek Lagoon allele at adjacent Arroyo de las Frijoles appears to indicate lack of successful movement from Pescadero south along the rocky coast to colonize the tiny southern population.

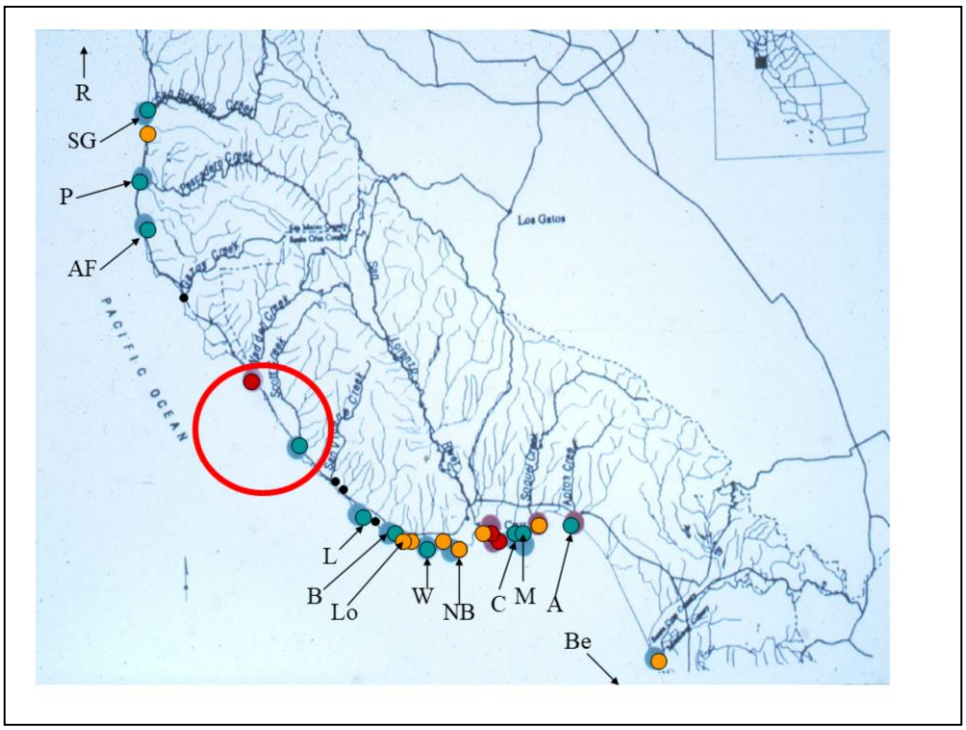
Pecadero Creek Lagoon is a large complex, but alteration of tidal dynanmics following bridge replacement and levee alteration has altered habitat conditions for gobies.

In the upper photo the sandbar regularly formed in summer providing calm back-waters suitable habitat for goby breeding throughout the closed embayment and in the flooded marshes produced by the closed sandbar.

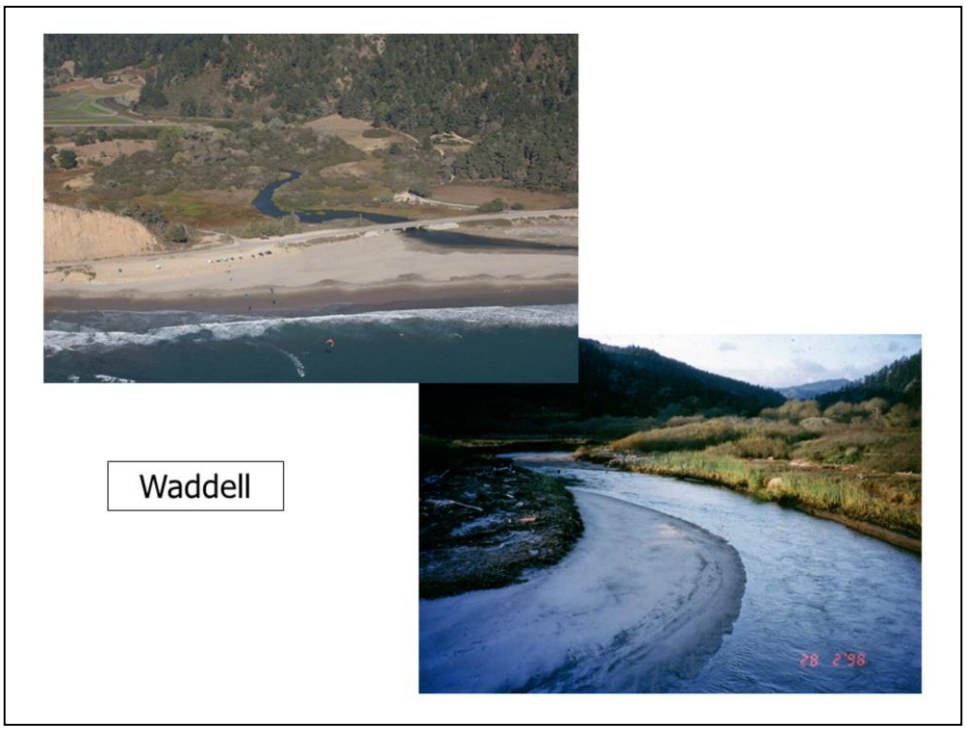
From the 1990's onward the lagoon has usually remained open in summer (closing in September), with gobies absent from the tidal embayment and restricted to upstream less tidal sites. The lack of summer bar formation results in drying of most of the complex in summer.

San Gregorio is large, but subject to summer sandbar breaching associated with recreation use. During floods, the incised channel upstream of the bridge provides a relatively poor flood refuge. The marsh on the north (left in picture) side may act as a high flow refuge (connected by a culvert). The marsh probably dries in droughts, so movement back and forth between the lagoon and the marsh may be important to maintain the tidewater goby population.

Arroyo de las Frijoles is a very tiny habitat that nearly dries in droughts. A reservoir immediately upstream and backwaters in the lagoon provide flood refuges to maintain this small, but apparently secure population.



Waddell and Scott creeks in northern Santa Cruz County are widely separated from occupied habitats north and south.



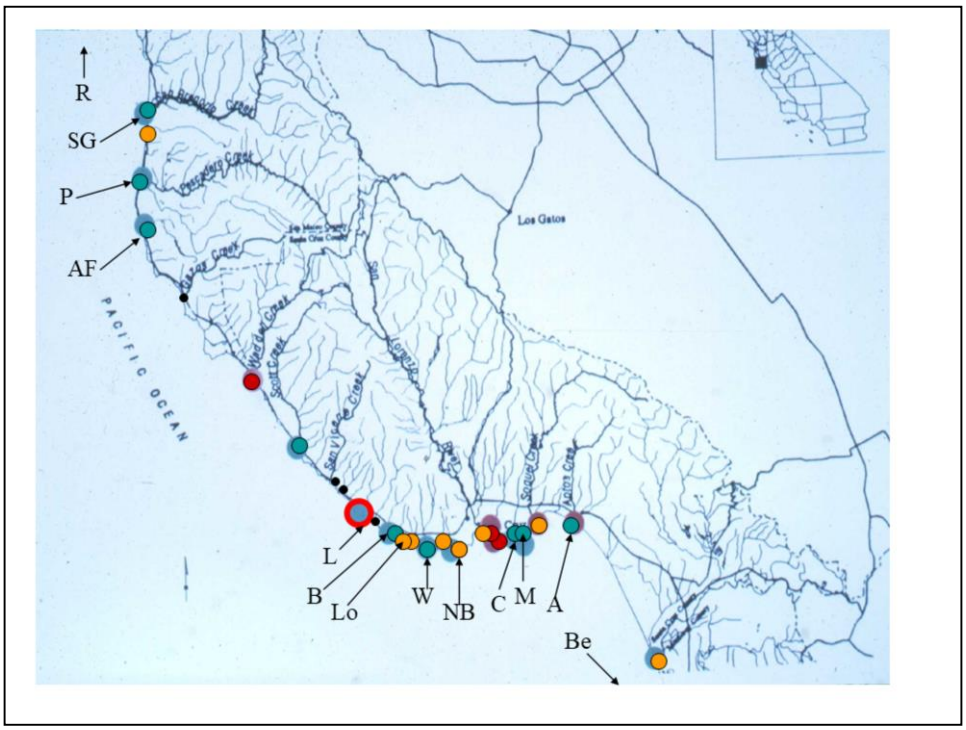
Waddell Creek lost its tidewater goby population during a flood in 1973. The channel was relatively incised, with little backwater habitat as flood refuge (possibly an effect of the Highway 1 Bridge). They remained absent through 1991.

Tidewater gobies (n=231) were introduced in 1991 from the drying main embayment of Scott Creek, with a letter permit from California Department of Fish and Game. TWG were common through 1994, but were severely reduced by the 1995 flood and were thought to have been absent from 1997 to 2000. However, gobies were rediscovered in 2012, so their "absence" was apparently due to scarcity and lack of recent sampling for them, rather than to loss of the population.

More recently, the meanders upstream of the bridge have widened (especially in 1999), providing improved refuges on the inside of the bends. Emergent vegetation and backwaters on the inside of the meanders should now provide sufficient habitat to maintain gobies during severe floods. Despite severe flooding in winter 2016, gobies were common that summer.

Tidewater gobies were “rediscovered” in 1987 in Scott Creek. Presumably they had persisted within the marsh complex, but were often rare in the main channel. The main stream channel/lagoon is subject to winter scour, but gobies persist in portions of the marsh and often in the adjacent upstream-connected pond (to the right). When the sandbar forms in summer, and is not artificially breached (as frequently occurs), the gobies (and steelhead) are able to become abundant in the impounded lagoon.

The straight, simple flood-prone main channel resulted from channel realignment when the Highway 1 Bridge was built in 1939. Bridge replacement provides the opportunity to restore a meandering, complex embayment with backwaters and residual spring depth. This would improve habitat linkages (between the marsh and the main channel) for gobies and also improve spring feeding habitat for coho salmon and steelhead.



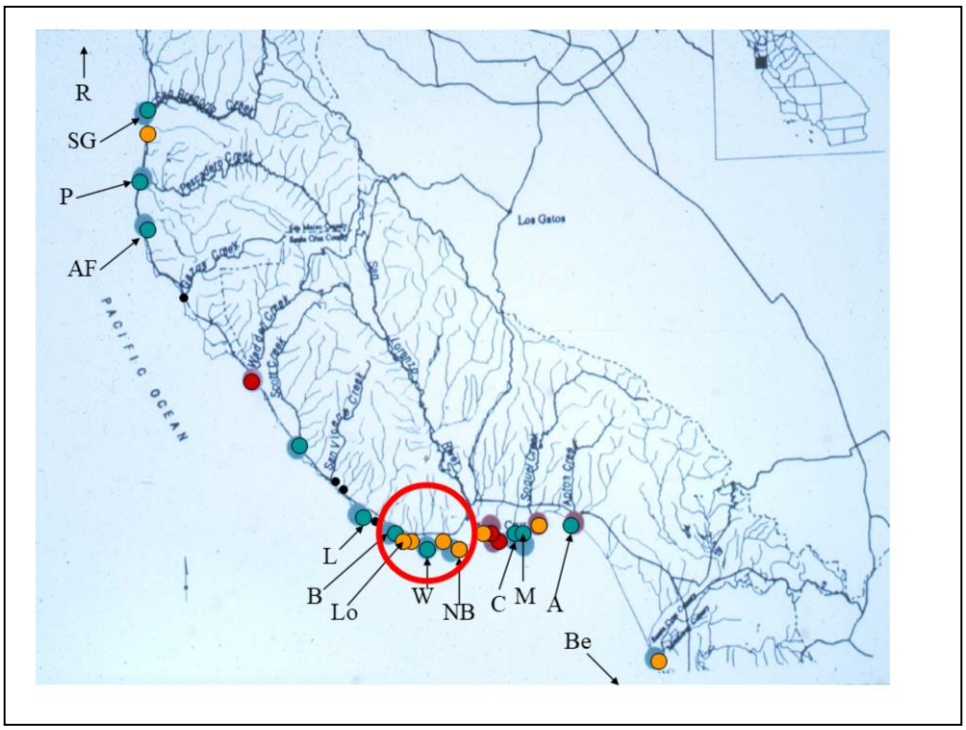
Laguna Creek lagoon is substantially south of Scott Creek and closer to Baldwin Creek, to the south. However, currents are to the south (and east) and coastal terrain is steep and rocky. Goby movement to Laguna is probably absent or severely restricted. Former possible goby populations, including at San Vicente and Liddell creeks, to the north, and Majors Creek, to the south, now lack habitat for gobies and cannot serve as stepping stones.

Laguna Creek is named for the large natural (but modified) off-channel pond to the southeast of the main channel. Diversions in the upper watershed formerly made the system subject to severe dry-back in drought years.

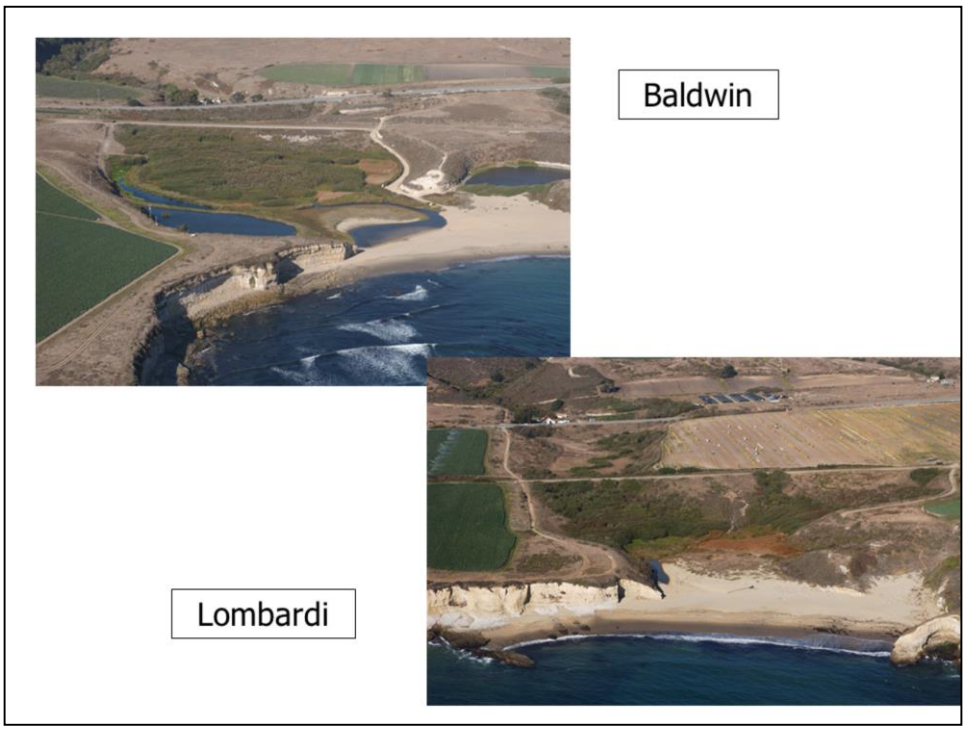
In 1987 the off-channel pond was dry, and almost all of the stream channel was dry in late summer and fall. The remnant surviving habitat was a small pool scoured at the base of an abandoned concrete seasonal dam. Efforts to sample the pool captured no gobies, and the population was suspected as extirpated.

However, tidewater gobies were abundant again following the 1987-1991 drought. The presence of a unique population mtDNA haplotype in Barlow's genetic study (2001) indicates that the population persisted through the drought, and the site is not an example of extirpation and colonization.

Bypass stream flows have been improved in the watershed, and the site has less risk of drying in drought. The off-channel pond provides the refuge against severe floods, but is subject to drying in dry years. Maintaining regular movement between the pond (which is also potential red-legged frog breeding habitat) and the stream channel is important for long-term population persistence.



A closely adjacent cluster of populations between Baldwin Creek and Moore's Creek (Natural Bridges) apparently constitutes a functioning metapopulation with occasional population losses and colonization. However, secure core populations (sources) have probably maintained the cluster in the past.



Baldwin Creek is a small, but secure complex. Off-channel agricultural ponds also serve as goby refuges. The complex channel provides secure flood refuge and abundant gobies survive even large winter floods.

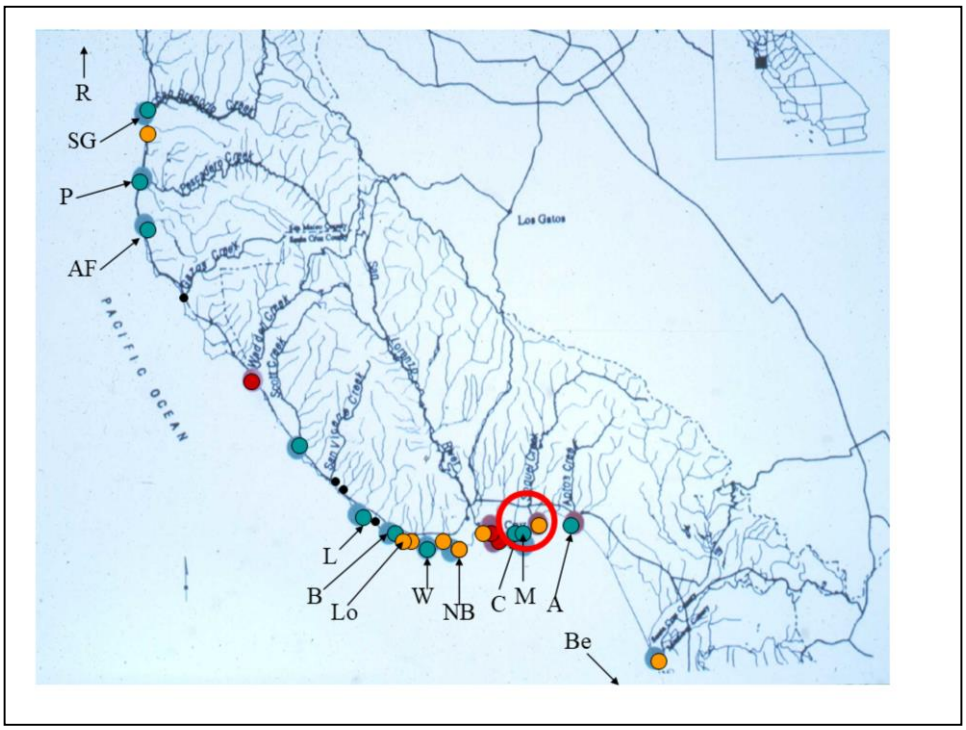
Nearby Lombardi Creek lagoon is at the mouth of a small drainage and subject to severe dry-back. The population probably regularly was lost in drought years and reestablished from Baldwin Creek. Excavation of ta larger residual pond by the California Department of Parks and Recreation has improved the persistence of this population.

Wilder Creek Lagoon provides secure, persistent habitat for gobies, with drought year persistence and winter flood refuge. The goby population is consistently high, including in spring following severe floods.

Old Dairy Gulch, immediately to the north (west) is tiny, dries in droughts, and is periodically reestablished by colonization.

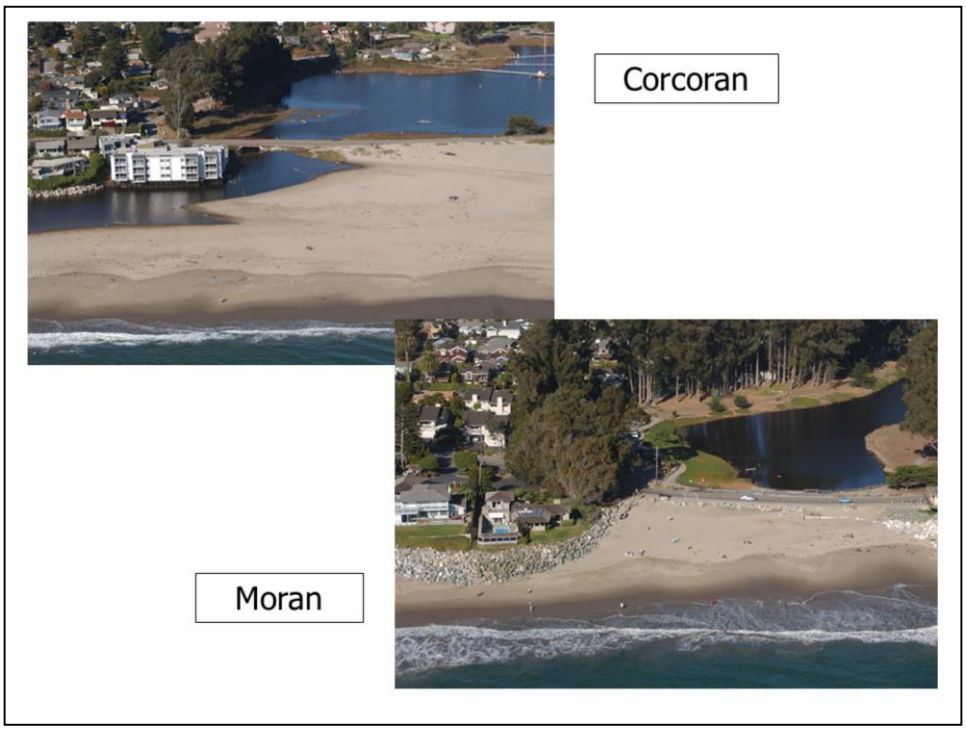
Younger Lagoon has usually had tidewater gobies, and the lack of gobies in some collection attempts probably reflects scarcity rather than absence. The watershed is small and the habitat is usually saline.

Moore's Creek Lagoon at Natural Bridges State Park receives runoff from a small watershed. Antonelli's Pond must fill and spill to provide runoff to the creek at the lagoon. During the 1987-1991 drought this rarely occurred and Moore Creek Lagoon dried to a few tiny isolated pools. The absence of successful goby collections at that time may reflect either loss of the population or extreme scarcity (as at Laguna). If lost, colonization of gobies from Baldwin and Wilder is likely.



Corcoran and Moran lagoons, east of Santa Cruz, occur in small, urbanized watersheds, so freshwater inflow is limited. These saline lagoons (often near sea water concentration) are closely adjacent, genetically nearly identical and appear secure.

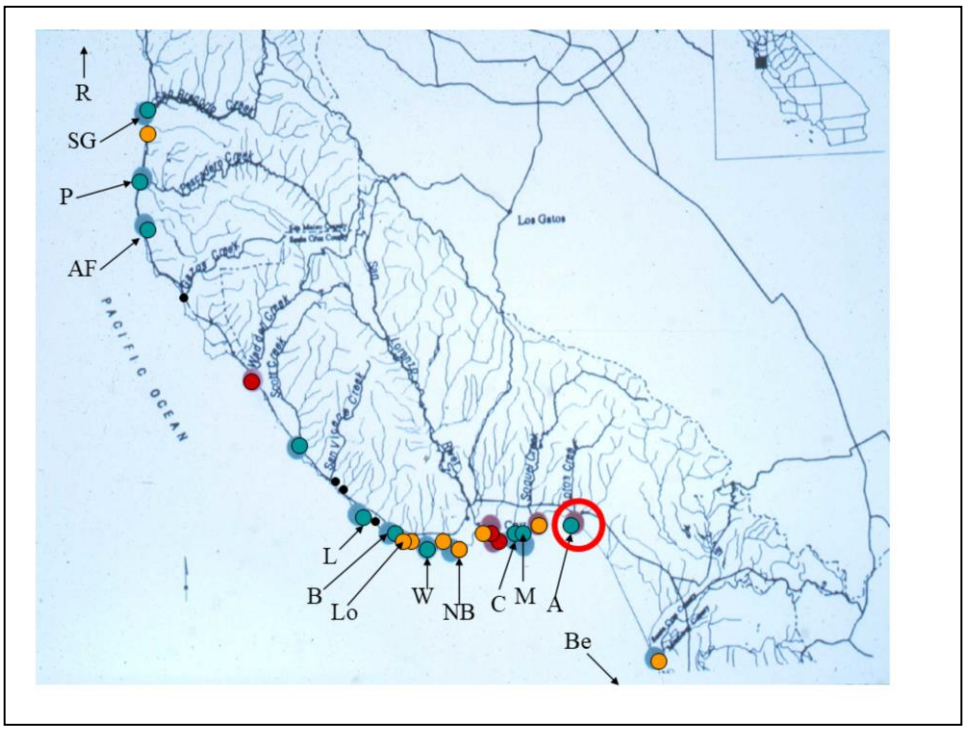
The two are probable sources for the tidewater gobies sometimes present at Soquel Creek lagoon.



Corcocan lagoon is much larger and is very secure, although it has been subject to sewage spills and artificial sandbar breaching. Even with the sandbar removed there is substantial complex residual depth in this large marsh complex.

Moran is quite small, can nearly dry in some years and is more prone to flooding (or removal of the sandbar leaving little residual habitat in large wave events). Gobies have sometimes not been captured at Moran, possibly due to loss or to rarity.

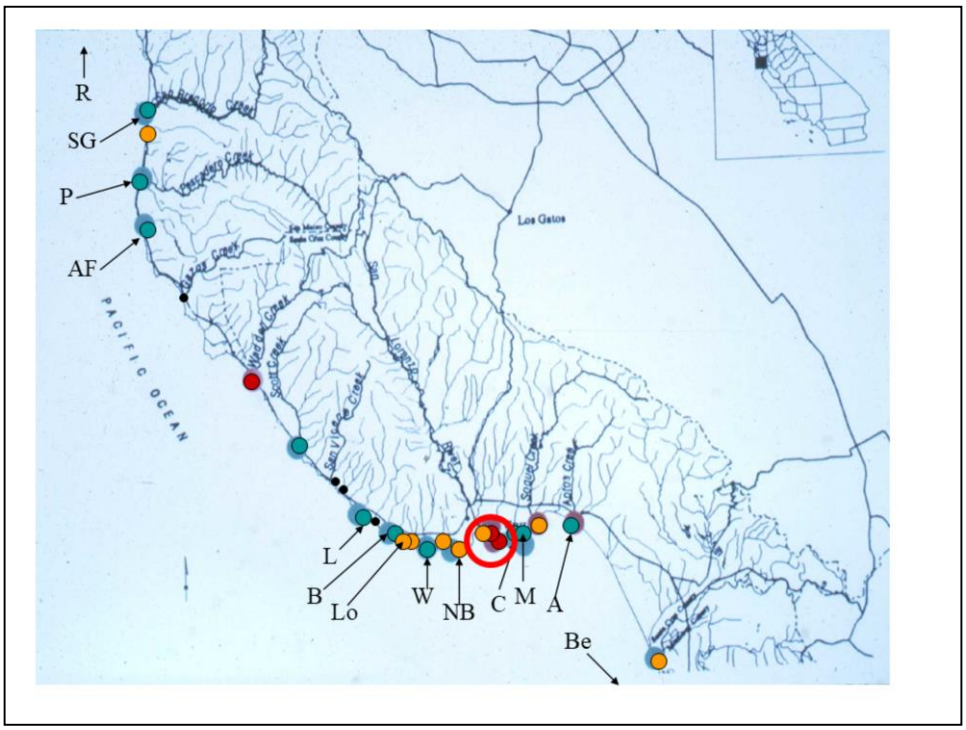
Soquel Creek lagoon is walled in by urban development, and no flood refuge is available in storm years. Gobies were common in 1990-1991 (drought years), but lost after the wetter winter/spring of 1992. Presence/absence has fluctuated among years with floods and with recolonization (from Corcoran?).



Aptos Creek lagoon is also surrounded by an urbanized landscape.

The stream channel is lined by walls, and during storms there appears to be little flood refuge. After the 1998 storms gobies were not collected. However, Aptos Creek gobies have a unique haplotype (Barlow 2001), so the population persisted through the floods, and was not lost and re-colonized. Rip-rap associated with a piling wall at the downstream end of the flood channel may serve as a fragile flood refuge.

The lagoon has been subject to sandbar breaching in the past, and a present controversy exists between threats to beach homes when the stream curves to the south. When the sandbar is breached straight out, winter refuge for gobies is threatened. Improved channel complexity and maintaining the summer sandbar are important for tidewater gobies at this site.

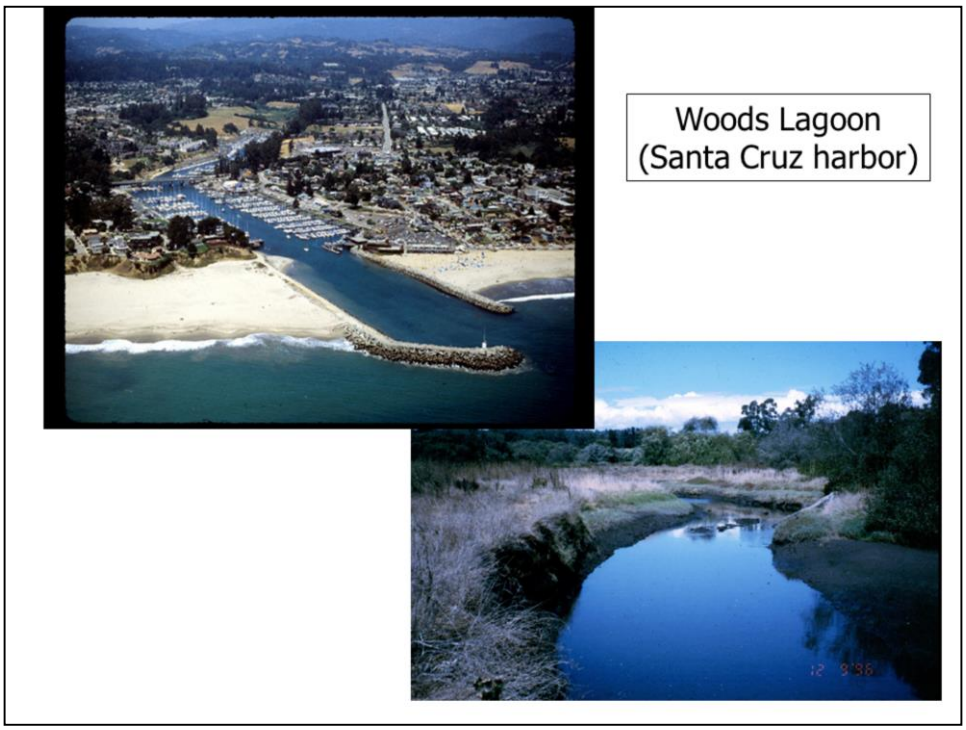


Three sites near Santa Cruz have lost tidewater gobies or may have intermittent populations.

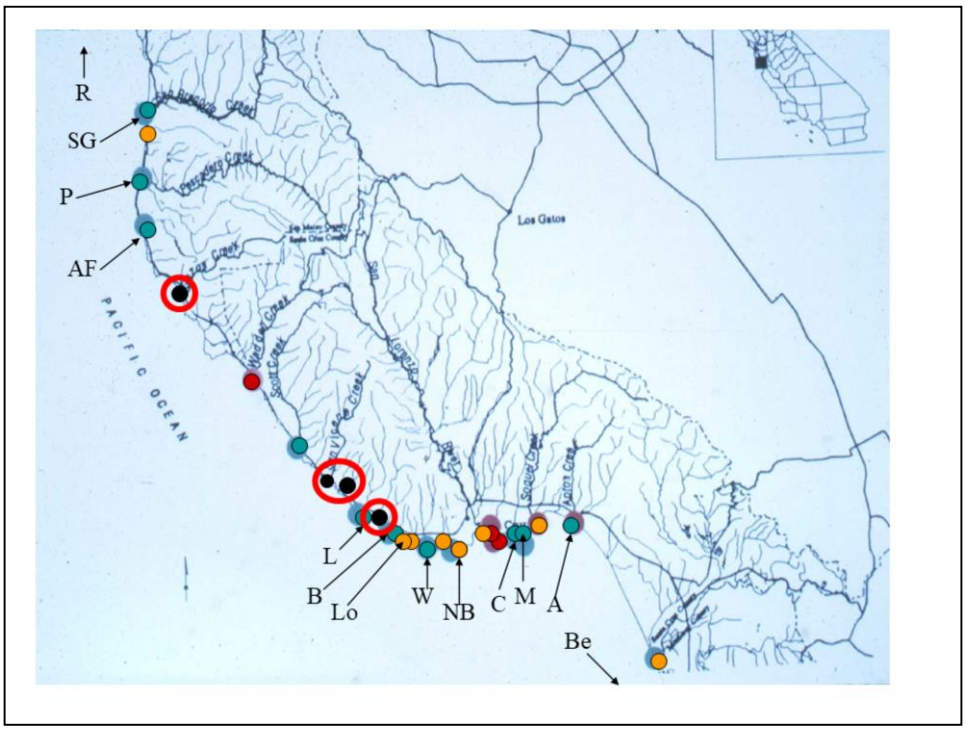
The San Lorenzo River channel has been channelized and levied for flood control. No gobies were captured during efforts in the 1980's and 1990's. However, gobies were found during upstream bank protection in the 2000's. Rip rap there may provide some winter flood protection, but the San Lorenzo River population may be periodically lost in severe storm years.

Schwan Lagoon originally had tidewater gobies, but the system has been modified into a permanent freshwater lake, with a highway serving as the dam. Gobies are absent in the presence of the introduced freshwater fish.

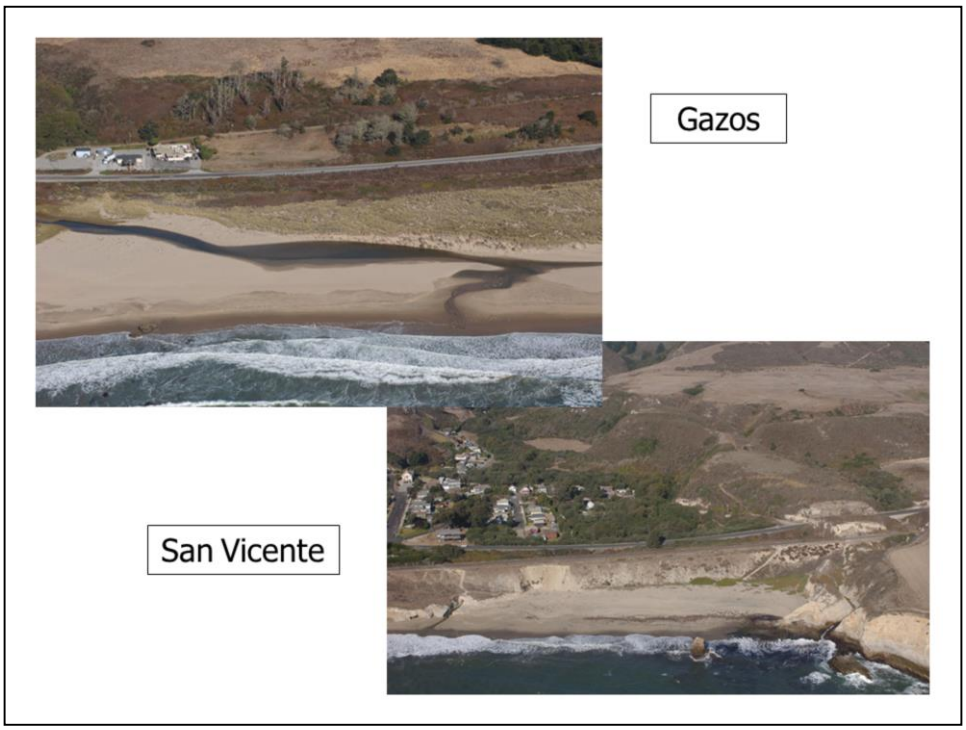
The two sites and Woods Lagoon (next page) previously provided connectivity between population north and south of Santa Cruz.



The goby population at Woods lagoon was lost when the system was modified for the Santa Cruz Harbor. The lack of calm, non tidal summer habitat prevents maintaing gobies at the site.



Previous potential goby sites that could have both maintained persistent populations and served as stepping stones between populations were lost prior to any record of gobies.

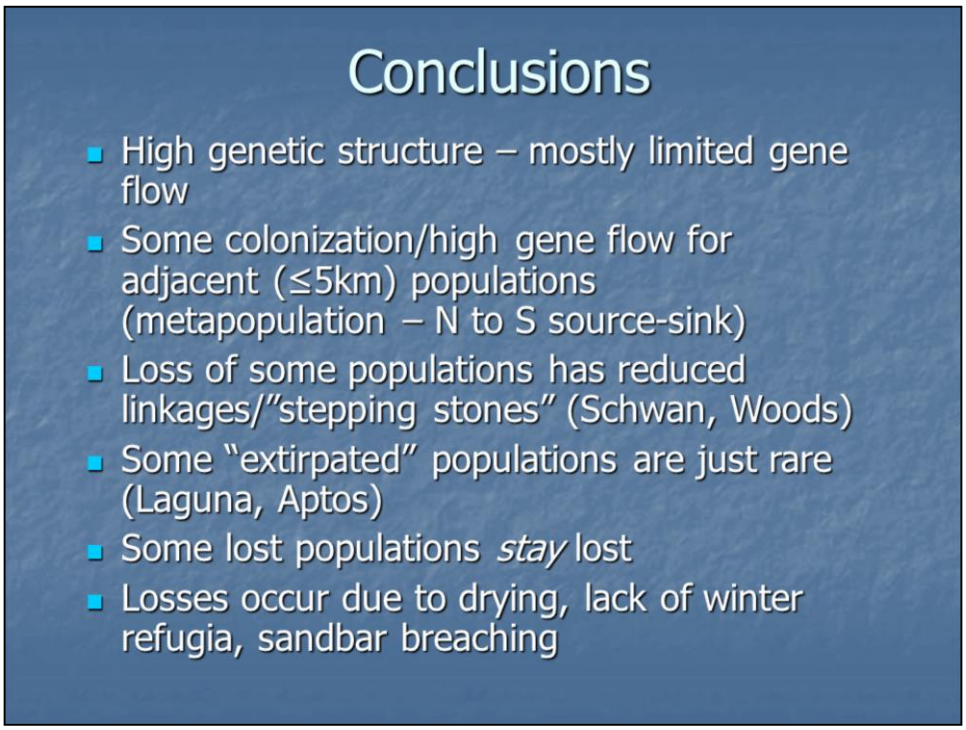


At Gazos Creek, the one potential goby site between those in San Mateo County and those in northern Santa Cruz County, there is no no refuge against winter floods. Confinement of the channel by Highway 1 may have reduced habitat complexity at the site. The site is also subject to regular artificial breaching in summer.

San Vicente and Liddell creek lagoons were lost by the construction of Highway 1 and a railroad embankment on the lower channels, providing tunnels that spill directly out on the beaches. The is now no space for lagoons.

Majors

Majors Creek provides a small summer impounded lagoon, but there is no apparent winter refuge against storm flows and wave events.



Most of the populations show differentiation caused by restricted movement among population.

Closely adjacent populations ($\leq$ 5 km) are genetically similar and may the only true classic metapopulations (Baldwin Creek south to Natural Bridges, north of Santa Cruz, and Corcoran and Moran Lagoons, south of Santa Cruz.)

There was probably more linkage prior to loss of potential stepping stone populations (Schwan, Woods, Gazos?).

Laguna, Aptos, Scott and possibly Natural Bridges are examples of populations that persisted as tiny remnants during droughts or floods, and probably do not represent extirpations and colonizations.

Waddell Creek lagoon lost gobies in 1973 and still lacked them in 1991 when they were artificially reintroduced from Scott Creek. They were thought to have been lost following storms in 1995-1998, but were rediscovered more recently. Increased channel meander and habitat complexity now apparently provides suitable backwaters during floods.

Pomponio Creek lacked gobies in the 1980's but they are now present, at least periodically, apparently colonizing from San Gregorio.

Threats still exists due to drying, lack of winter refugia, sandbar breaching and development that simplifies channels. However, the extant populations are those which have survived those threats through the 1987-1991 droughts and 1995, 1998 floods.

Management Implications

- Manage by short, linked coastal segments
- Prioritize source populations in source-sinks
- Re-establish "stepping stone" populations
- Establish/reestablish backup populations
- Protect/restore winter backwaters, summer sandbars, summer inflow

Acknowledgments

- DNA samples from Dave Jacobs, UCLA
- Sampling assistance from Ruth Sundermeyer, Michelle Leicester, Matt Franz, Brent Spencer, Tiffany Hernandez
- Aerial photos from California Coastal Records Project (www.californiacoastline.org), Copyright © 2005 Kenneth & Gabrielle Adelman. All rights reserved; used by permission.