

## **Biological Tags for Stock Separation in Pacific Herring (*Clupea harengus pallasii* Valenciennes) and the Possible Effect of "El Niño" Currents on Parasitism**

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### **ABSTRACT**

A ten-year study of Pacific herring off northern California showed that parasites could be used to separate the spawning stocks of San Francisco Bay and Tomales Bay. The distribution of the definitive hosts of the respective parasites suggest that the Tomales Bay fish are offshore and the San Francisco Bay fish onshore. The similarity in parasitism between San Francisco Bay and the nonspawning population in Monterey Bay suggests that these two populations represent a single stock. However, more samples are needed to confirm this suggestion.

Periodic warm-water "El Niño" currents occur off the California coast. Some diet-related parasites increased during the 1983-84 event. This increase may have been related to the influx of large numbers of marine mammals escaping the warm southern California waters.

### **INTRODUCTION**

The Pacific herring (*Clupea harengus pallasii* Valenciennes) is an important roe fishery in central California. The fish enter San Francisco and Tomales Bays from December to March to spawn. They remain in the bays one to three weeks without feeding, spawn and leave the bay within days. The eggs hatch in approximately two weeks. The juveniles stay in the bays throughout the summer and into October. They remain offshore for two years, mature and then return to spawn for the first time. The spawning population in San Francisco Bay (50,000-70,000 tons) is approximately 10 times that of Tomales Bay (500-5,000 tons) (Jerome Spratt, Calif. Dept. Fish and Game, personal communication). Herring are caught in Monterey Bay in the summer. There is no significant spawning in Monterey Bay and this is a small, incidental fishery.

Currently, the California Department of Fish and Game does not have sufficient information to determine whether the two spawning areas represent separate or one breeding stock. If the two areas could be

shown to be a single breeding stock, the quotas for the two areas could be combined. Commercial anglers would be free to fish both bays until this combined quota was met. However, to prevent potential overfishing in either bay, the two areas must be regulated separately. Presently, anglers are assigned to one of the two bays and are restricted to that bay regardless of the abundance of herring there that season. During the 1989-1990 season the San Francisco Bay fishery was valued at approximately \$11 million and the Tomales Bay fishery at only \$150 thousand. The purpose of this study was to use parasites to determine whether San Francisco and Tomales Bays represent separate breeding stocks and if these stocks remain separate while at sea.

During this ten-year survey, central California experienced a significant "El Niño" event. The data was examined to determine possible relationships between increased water temperatures and fish parasitism.

#### METHODS AND MATERIALS

Pacific herring (*Clupea harengus pallasii*) were collected from 1980-81 to the 1989-90 in San Francisco, Tomales and Monterey Bays (Monterey Bay 1982-83, 1987-88 and Tomales Bay 1989-90 excepted) and frozen (Figure 1). Fish were aged using a growth curve (Spratt 1981). All fish were two year olds. In the 1980-81 season, approximately 100 fish from both San Francisco and Tomales Bays and 20 from Monterey Bay were surveyed for parasites as potential candidates as biological tags. Thereafter, 30 fish were sampled from each bay per season.

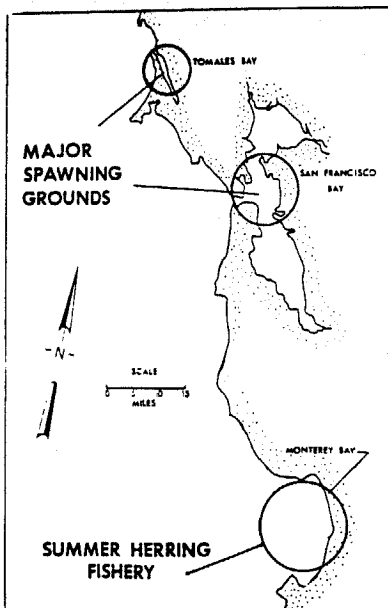


Figure 1. Herring fishery off central California.

Most fish examined in the 1980-81 survey contained both larval nematodes, *Contracaecum* sp. and *Hysterothylacium* sp. Since it is relatively time consuming to distinguish between the two genera for each specimen, and most fish contained both, these genera were combined into *Contracaecum* sp./*Hysterothylacium* sp. category.

Differences in prevalence were compared by doubling the standard deviation to account for approximately 90% of the variation. The differences in intensity was compared using a Mann-Whitney U test.

#### RESULTS

The results of the 1980-81 parasite survey of herring from Monterey, San Francisco and Tomales Bays are given in Table 1. From this survey and the average dominances (Table 2), four candidates were selected to be monitor for nine years. They were *Lacistorhynchus dollfusi* (Cestoda), *Anisakis simplex* and *Contracaecum* sp./*Hysterothylacium* sp. (Nematoda) and *Parahemirus merus* (Digenea).

Parasites and Infection Loci	Tomales Bay N=28♂, 72♀	San Francisco Bay N=50♂, 72♀	Monterey Bay N=17♂, 7♀
<b>Acanthocephala</b>			
<b>Rhadinorhynchidae</b>			
<i>Rhadinorhynchus trachuri</i> Harada, 1935 intestine, stomach, caeca	0	p=1.0 l=1.0	0
<b>Cestoda</b>			
<b>Lacistorhynchidae</b>			
<i>Lacistorhynchus dollfusi</i> Beveridge and Sakanari, 1967 muscle	P=62 l=1.97(1.4)	P=96.0 l=9.9(6.0)	P=70.8 l=3.6(9.1)
<b>Copepoda</b>			
<b>Bomolochidae</b>			
<i>Bomolochus cuneatus</i> Fraser, 1920 gills, opercular cavity	P=8.0 l=1.2(.5)	P=16.0 l=1.1(.35)	P=50.0 l=1.6(.63)
<b>Caligidae</b>			
<i>Caligus clemensi</i> Parker and Margolis, 1964 gills, opercular cavity	0	P=5.0 l=1.2(.58)	0
<b>Digenea</b>			
<b>Hemiuridae</b>			
<i>Parahemiurus merus</i> (Linton, 1910) Woolcock, 1935 intestine, stomach, caeca	P=4.0 l=1.0	P=1.0 l=10.0(6.3)	P=95.8 l=7.0(6.3)
<b>Bucephalidae</b>			
(metacercaria) fins, nose, head	*P=♂ 97.1 ♀ 81.1 l=5.0(4.9)	*P=♂ 76.0 ♀ 46.0 l=2.5(1.5)	P=50.0 l=2.6(2.3)
<b>Nematoda</b>			
<b>Anisakidae</b>			
<i>Anisakis simplex</i> (larva), (Rudolphi, 1802) muscle, mesentery	P=93.0 l=8.8(7.5)	P=61.0 l=4.1(3.0)	P=16.7 l=1.7(1.5)
<i>Contracaecum</i> sp./ <i>Hysterothylacium</i> sp. (larva) caecae, mesentery	P=99.0 l=6.9(4.3)	P=96.0 l=10.6(6.9)	P=100 l=10.7(8.9)
<b>Protozoa</b>			
<b>Myxospora</b>			
<i>Ceratomyxa auerbachii</i> Kabata, 1962 gall bladder	P=44.0	P=52.0	P=33.3
<b>Coccidia</b>			
<i>Eimeria nishin</i> Fujita, 1934 testes	P=21.0	P=36.0	P=16.6
<i>Goussia clupeaum</i> (Theohani, 1894) liver	P=44.0	P=55.0	P=70.0

Table 1. Preliminary Parasite Survey 1980-1981. (N=number hosts; P=prevalence; Intensity (standard deviation); \* = significant differences between sexes, Mann-Whitney U P<.05).

	<u>Anisakis simplex</u>	<u>Contracaecum/Hyterothylacium</u>	<u>Lacistorhynchus dollfusi</u>	<u>Parahemimerus merus</u>
Tomales Bay	35.26%	33.20%	7.45%	0.28%
San Francisco Bay	10.05%	38.31%	37.21%	0.44%
Monterey Bay	1.22%	43.04%	6.82%	31.42%

Table 2. Average dominances of select parasites.

Lacistorhynchus dollfusi

The prevalence of infection (number infected/number examined) was similar between San Francisco and Monterey Bays and both were two standard deviations greater than Tomales Bay throughout the study (Figure 2).

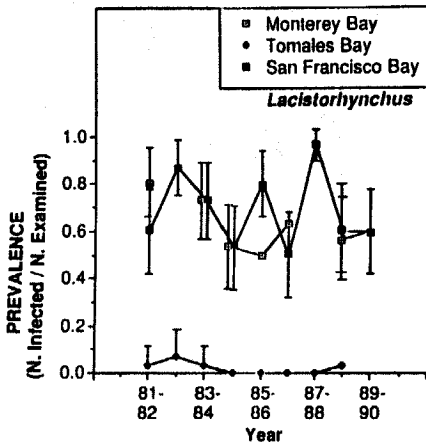


Figure 2. Prevalence of infection of L. dollfusi (error bar = 2 SD)

of infection is significantly greater in Tomales Bay fish than San Francisco and Monterey Bays (Figure 7). The intensity of infection in Monterey Bay significantly increased with age ( $R^2=.541$ ).

Contracaecum sp./Hyterothylacium sp.

There was no significant difference in prevalence among the bays (Figure 8). The prevalence of infection in Monterey Bay was 100% among two to four-year-olds. The intensity was similar between San Francisco and Monterey Bays and significantly different between Tomales and San Francisco Bays (Figure 9). The intensity increased in Monterey Bay fish with age ( $r^2=.39$ ).

The prevalence increases with age of the host. There is a significant increase between the two and the three and four-year-old from Monterey Bay fish (Figure 3). There was no significant difference in the intensity of infection (number parasites/infected fish) among the three bays (Figure 4).

Anisakis simplex

The prevalence of infection was similar between Monterey and San Francisco Bays and both were consistently two standard deviations lower than Tomales Bay (Figure 5). The prevalence, increases with host age (Figure 6). Similar to the prevalence, the intensity

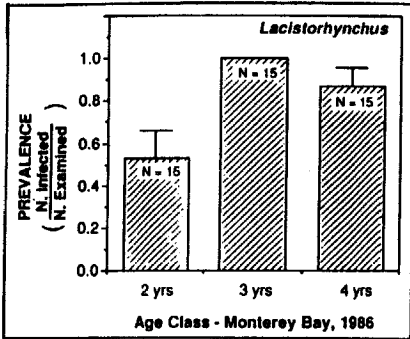


Figure 3. Prevalence of *L. dollfusi* by age class (error bars - SD)

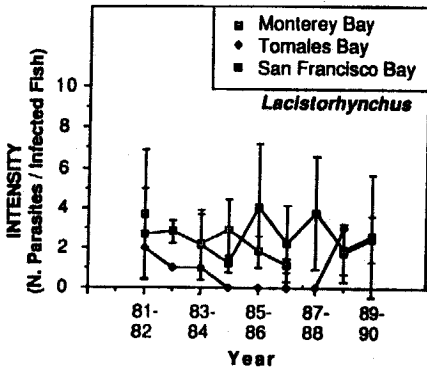


Figure 4. Intensity of infection *L. dollfusi* (error bars - SD)

content of these two stocks were different throughout the nine seasons. Dougal Scott (Cabrillo College, Aptos, CA) examined herring collected from the 1980-81 survey for genetic differences between San Francisco and Tomales Bays using gel electrophoresis. Six loci were examined from muscle tissue: PGI, PGM, ADA; PEP-2, LDH-1 and LDH-2. Scott found no significant difference in the genotypes and frequencies of alleles between these two bays. In fact, neither differed significantly from samples reported from Seattle, Washington (personal communication).

MacKenzie summarized the use of parasites as biological tags in fish populations (1983) and herring in particular (1987). MacKenzie (1987) list twelve studies in which parasites had been successfully used in herring population studies.

The consistent difference in the prevalence of *L. dollfusi* infections between San Francisco and Tomales Bays suggest that these stocks are separate and repeatedly return to spawn in the same bay. As mentioned, adult herring do not feed on the spawning grounds. Therefore, fish

### Parahemius merus

The prevalence of infection between Monterey and San Francisco Bays were similar and generally two standard deviations greater than Tomales Bay (Figure 10). The prevalence decreases with age in Monterey Bay between two and four year olds (Figure 11). There was no significant difference in intensity among the three bays (Figure 12).

### Effects of "El Niño" on Parasitism

The prevalence and intensity of *Anisakis simplex* (Figures 5 and 7 respectively) and the intensity of *Contracaecum* sp./*Hysterothylacium* sp. infections (Figure 9) increased in 1984-85 collections.

### DISCUSSION

Spratt (1981), using a growth curve, showed that Tomales Bay fish are larger than those from San Francisco Bay, hence might separate stocks. Graham Worthy (Long Marine Lab., University of California, Santa Cruz, in preparation) compared the total caloric content of the Tomales and San Francisco Bay herring collected from 1981-82 to 1989-90 during this present study. Worthy showed that the caloric

become infected either during their first summer on the nursery grounds or while at sea. If fish become infected only as juveniles on the nursery grounds, the prevalence of infection would not increase with age. The prevalence, however, increased with age. This suggests that they are becoming or continuing to be infected while at sea. The life cycle of *L. dollfusi* includes the adult in sharks, the proceroid larva in microcrustaceans and the plerocercoid larva in fish (Sakanari and Moser 1989). The increased prevalence of these larva with age, and the fact that adult herring do not feed on the spawning grounds, suggests that Tomales Bay and San Francisco Bay stocks do not mix while at sea.

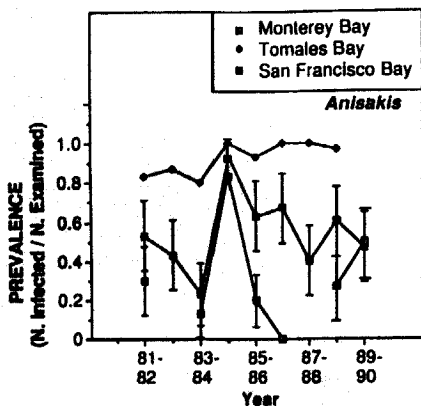


Figure 5. Prevalence of infection of *A. simplex* (error bars = 2 SD)

The similarity in the prevalence of infection between San Francisco and Monterey Bays suggest that the fish which are caught in the summer in Monterey Bay are part of San Francisco Bay spawning stock. This possibility needs further investigation because the size of the San Francisco Bay stock is an order of magnitude greater than Tomales Bay. If both Tomales and San Francisco Bay stocks were found in the summer in Monterey Bay, the disproportionate number of San Francisco Bay fish present would bias the samples. Future collections in Monterey Bay will be increased by a factor of ten to control for this difference in stock sizes.

Adult *A. simplex* are found in cetaceans. The eggs pass into the sea water and hatch. They are eaten by microcrustaceans, which are in turn consumed by fish or macroinvertebrates such as squid. If a fish eats an infected squid or fish, the larval nematodes will reinfect the new host. Serial infections result in rapid increases in the prevalence and intensity of infections.

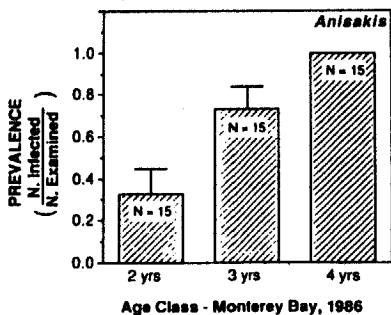


Figure 6. Prevalence of *A. simplex* by age class (error bars = SD)

The prevalence and intensity of *A. simplex* in Tomales Bay herring are greater than those from San Francisco and Monterey Bays. The rationale for these differences are the same as *L. dollfusi*. Consistent differences in prevalence and intensity suggest that Tomales and San Francisco Bays are separate spawning stocks and repeatedly spawn in the same bay. The lack of feeding by adults on the spawning grounds and increased infections with age suggests that these stocks do not mix while at sea. The similarity between San Fran-

cisco and Monterey Bay infections may indicate that they are the same stock. However, as with *L. dollfusi*, larger future collections in Monterey Bay are needed to confirm this possibility.

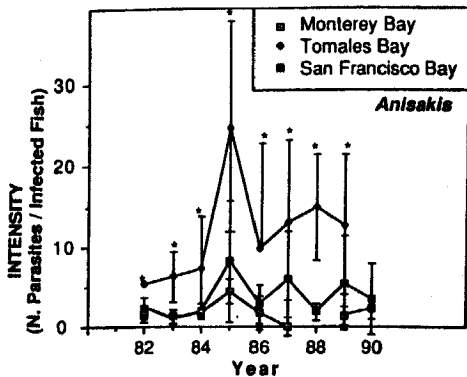


Figure 7. Intensity of infection of *A. simplex* (error bars - SD; \* - Mann-Whitney U test,  $p < 0.05$ )

Tomales and San Francisco Bays may indicate the adults are feeding in different areas.

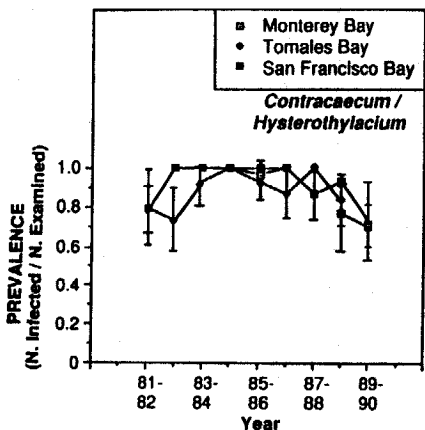


Figure 8. Prevalence of infection of *Contracaecum* sp./*Hysterothylacium* sp. (error bars = 2 SD)

Adult *Contracaecum* are found in pinnipeds and marine birds and adult *Hysterothylacium* in marine fish. In other aspects, the life cycles are similar to that of *Anisakis*. The variety of definitive hosts for *Contracaecum* sp./*Hysterothylacium* sp. may be the reason most fish were infected with these parasites. The high prevalence of infection in the two to four-year-olds indicates that the larva are long lived and/or the fish continue to become infected after they leave the nursery grounds. The difference in the intensity of infections between

The differences in infections of *L. dollfusi*, *Contracaecum* sp./*Hysterothylacium* sp. and *A. simplex* between Tomales and San Francisco Bays have suggested that these two stocks are separate herring, repeatedly spawn in the same bay and remain separate while at sea. The latter suggestion is supported by the distribution of the definitive hosts for *A. simplex* are more offshore than pinnipeds and marine birds (definitive hosts for *Contracaecum* sp.) and elasmobranchs (*L. dollfusi*). Onshore and offshore fish (definitive hosts for *Hysterothylacium* sp.) abundance is more difficult to estimate. Given the geographic distribu-

tion of the various definitive hosts, it might be suggested that Tomales Bay fish become infected offshore with *A. simplex* and San Francisco Bay fish are infected with *L. dollfusi* and *Contracaecum* sp. onshore. These correlations depend on discrete onshore and offshore population of infected intermediate hosts. These populations could maintain by the north-south currents found off central California. Interestingly, Cannon (1977a, b) describe a similar

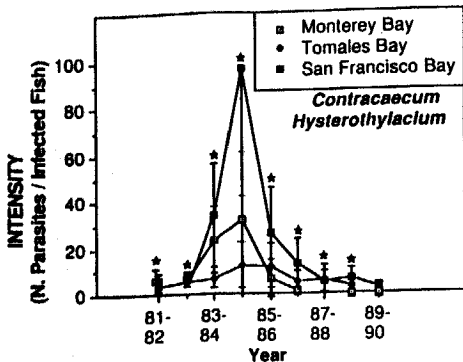


Figure 9. Intensity of infection of *Contracaecum* sp./*Hysterothylacium* sp. (error bars - SD; \* = Mann-Whitney U test,  $p < 0.05$ )

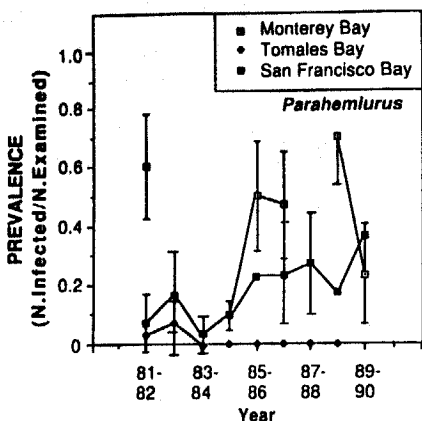


Figure 10. Prevalence of infection of *P. merus* (error bars - 2 SD)

classes and suggested they move into San Francisco Bay to spawn as they mature.

In 1983-84 central California experienced "El Niño" currents from South America. The average water temperature rose to above 16°C from an average of approximately 14°C. The herring fishery significantly decreased, as did the herrings' body condition factor, mean length and weight (Spratt 1987). Fish collected during 1984-85 season had spent much of their life in the warm "El Niño" currents. The increase in prevalence and intensity of *A. simplex* and the intensity of *Contracaecum* sp./*Hysterothylacium* sp. infections in 1984-85 may be related to the effects of these currents. During this "event", there was a significant increase in the influx from southern California of California sea lions on the Farallon Islands (David G. Ainley, Pt. Reyes Bird Observatory, personal communication). The sea lions had moved north to escape

correlation in inshore and offshore fish off Queensland, Australia. *Anisakis* was found in open water fish, *Contracaecum* in inshore shallow water fish and *Hysterothylacium* (-*Thynnascaris*) had an intermediate distribution.

The life span of the adult *Parahemilurus merus* most probably is less than one year. The decrease in prevalence with age may reflect a change in the diet of the herring as they get older. Similar to the above parasites, the difference between the prevalence of *Parahemilurus merus* infection in Tomales and San Francisco Bay fish suggest they are separate spawning stocks and remain separate while at sea. The similarity between San Francisco and Monterey Bay infections suggest they are the same stock but, as mentioned, needs farther sampling. However, the higher prevalence of infection in Monterey than San Francisco Bay may strengthen the latter suggestion. If fish are infected with this seasonal parasite relatively soon after spawning, more parasites will be present in the fish in the summer in Monterey Bay than in the winter in San Francisco Bay. By Winter, most of the parasites have died. Miller and Schmidtke (1956) noted that the summer Monterey fishery is predominantly the younger age

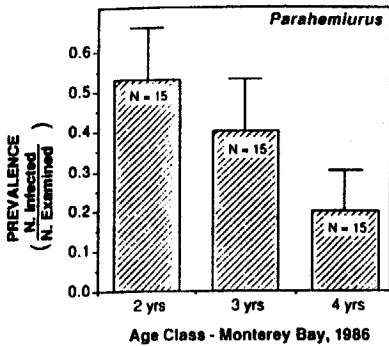


Figure 11. Prevalence of *P. merus* by age class (error bars = SD)

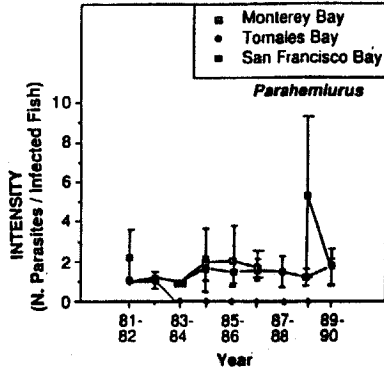


Figure 12. Intensity of infection of *P. merus* (error bars = SD)

unusually warm southern California temperatures. The Monterey Bay recorded new northern range extensions for several cetaceans and large numbers of bottlenose dolphins. These animals had followed the warm currents from south of the Mexican border. The rise in *A. simplex* infections may be due to increased numbers of cetaceans during this period. The increase in *Contracaecum* sp. may have been the result of the influx of large numbers of sea lions.

The possible relationship between "El Niño" and fish parasitism has also been suggested for rockfish off British Columbia (John Holmes, University of Alberta, personal communication). There was a marked increase in intestinal digenetic trematodes at this time. Holmes suggest that the warmer water may have increased the metabolism of the fish, hence they consumed more food and more infected intermediate hosts.

In summary, select parasites appear to be useful in separating the San Francisco and Tomales Bay spawning stocks and suggest that these stocks repeatedly spawn in the same bay and remain separate while at sea. Further collections are needed to determine if San Francisco and Monterey Bay fish represent a single stock. There is some evidence that "El Niño" may have affected fish parasitism off central California.

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