

**Biological Invasions in the
San Francisco Estuary:
A Comprehensive Regional Analysis**

by

Andrew Neal Cohen

**A dissertation submitted in partial satisfaction of the requirements for the
degree of Doctor of Philosophy in Energy and Resources,
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Committee in charge:

**Professor John Harte, Chair
Professor James T. Carlton
Professor William B. N. Berry
Professor Richard P. Norgaard**

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PLATYHELMINTHES

Alloglossidium corti (Lamont, 1921) [DIGENEA]

SYNONYMS: *Plagiorchis corti* Lamont, 1921
Plagiorchis ameiuensis McCoy, 1928
Alloglossidium kenti Simer, 1929

Although it has been recorded a few times from centrarchids (Hoffman, 1967), *Alloglossidium corti* is primarily a parasite of catfish, and in California has been reported only from catfish. Since all California catfish are introduced from the central or eastern United States, *A. corti* is undoubtedly introduced from there as well.

Haderlie (1950, 1953) reported *A. corti* to be rare and possibly accidental on white catfish (*Ameiurus catus*, on 1 of 109 examined) and occasional on brown bullhead (*Ameiurus nebulosus*, on 6 of 301 examined, with all infected fish from Clear Lake) in California in 1947-50. It was found on white catfish collected in the Delta in 1966-67 (Edwards & Nahhas, 1968) and 1972-73 (Hensley & Nahhas, 1975). It has been reported from New York (report published in 1934), Wisconsin (1947), British Columbia (1954), Alabama (1957) Iowa (1958) and Idaho (1959) (Hoffman, 1967; Williams & Dyer, 1992). In these places snails in the genus *Helisoma* serve as first intermediate hosts and crayfish or naiads of mayflies or dragonflies are the second intermediate hosts (Haderlie, 1950).

Atractolytocestus huronensis Anthony, 1958 [CESTODA]

This tapeworm has been reported only from North America, and only from carp *Cyprinus carpio*, which is native to Eurasia. Of the various species in the 12 genera that make up the subfamily Lytocestinae of the family Caryophyllaeidae, only *A. huronensis* and the introduced tapeworms *Khawia iowensis* (discussed below) and *Khawia sinensis* have been reported from North America (Calentine & Ulmer, 1961; Williams & Sutherland, 1981), both also parasites of *Cyprinus carpio*. *A. huronensis* is undoubtedly a Eurasian species as well.

A. huronensis has been reported in Michigan (1958), Oklahoma (1964) and possibly Washington (1953, as *Capingens* sp.) (Hoffman, 1967), and in Oregon (1977-79; Williams & Sutherland, 1981) and Iowa (Sutherland, 1989). It was found in one of 50 carp collected in the Delta in 1972-73 (Hensley & Nahhas, 1975).

Cleidodiscus pricei Mueller, 1936 [MONOGENEA]

Mizelle et al. (1961) found this common gill parasite of North American catfish on white catfish, *Ameiurus catus*, in the Sacramento River drainage by 1961; Miller et al. (1973) found it on five species of catfish in southern California reservoirs in 1966; and Hensley & Nahhas (1975) found it in white catfish (on 6 out of 137 fish), black bullhead (*Ameiurus melas*, 7 of 33 fish), striped bass (*Morone saxatilis*, 1 of 81 fish, new host record) and warmouth (*Lepomis gulosus*, 1 of 7 fish, new host record) in the Delta in 1972-73. *C. pricei* has been collected from all six of the catfish species that have been introduced to California, and since there are no native catfish in California it was undoubtedly introduced with one or more of them from the eastern or midwestern United States.

Since Haderlie (1953) did not find this trematode on 2,010 fish collected from various California sites in 1947-50, including 410 catfish, it may have been imported with one of the later but pre-1966 catfish introductions or reintroductions: with yellow bullhead *Ameiurus natalis* (reportedly introduced into California in 1874, but absent outside of the Colorado River drainage in 1942; then rare but present in various parts of California by 1984—Neale, 1915; Moyle, 1976b; Curtis, 1949; McGinnis, 1984); or with channel catfish *Ictalurus punctatus* (variously reported as planted in the Delta watershed in 1874 and 1891 and in southern California in 1895; established in the Colorado River since about 1920 and introduced from there to the rest of California; first successfully establishment after many attempts in 1925; and planted in the Sacramento drainage between 1925 and 1930 but not caught there until 1942—Smith, 1896; Shebley, 1917; Curtis, 1949; Miller, 1966b; Moyle, 1976b; Herbold & Moyle, 1989).

Cleidodiscus pricei has been recorded from various catfish species in Florida (report published in 1936), Louisiana and Oklahoma (1938), Tennessee (1943), Ontario (1944), Wisconsin (1945) and Virginia (1952) (Hoffman, 1967). It was introduced to the U. S. S. R. (by 1953), Hungary and Poland with North American catfish, embryonic catfish or catfish eggs (Hoffman, 1970; Hoffman & Schubert, 1984; Bauer, 1991).

In a study of monogean gill parasites of largemouth bass in a pond near Sacramento, Mizelle & Crane (1964) concluded that such parasites show good survival of the conditions incurred during transport of their hosts over long distances (i. e. from east of the continental divide into California).

Corallobothrium fimbriatum Essex, 1928 and *Corallobothrium giganteum* Essex, 1928 [CESTODA]

Both of these catfish tapeworms were collected in Clear Lake, California in 1947 and 1949 (Haderlie, 1953), in southern California reservoirs in 1966 (Miller et al., 1973), and in the Delta in 1966-67 (Edwards & Nahhas, 1968) and 1972-73 (Hensley & Nahhas, 1975). Although Haderlie (1950, 1953) found each of these tapeworms to be host specific as mature worms (*C. fimbriatum* in 150 of 301 brown bullhead, largest worms over 50 mm long; *C. giganteum* in 45 of 109 white catfish, largest worms over 300 mm long), both species were subsequently collected in California in white catfish, channel catfish and black bullhead. All of these catfish were introduced from the eastern or midwestern United States, which was undoubtedly the source region for the parasites. These tapeworms have been collected from five additional species of ictalurid catfish in the eastern and midwestern states (Hoffman, 1967; Hoffnagle et al., 1990).

In the tapeworms' native region, copepods in the genus *Cyclops* are reported as first intermediate hosts, with minnows (e. g. *Noropis blennius*) possibly serving in some cases as second intermediate hosts (Haderlie, 1950; Hoffman, 1967).

Dactylogyrus extensus Mueller & Van Cleave, 1932 [MONOGENEA]

SYNONYMS: *Dactylogyrus solidus*

Dactylogyrus extensus is a Eurasian gill parasite of the common carp, *Cyprinus carpio* (Hoffman & Schubert, 1984). Haderlie (1953) examined 2,010 fish in 36 species collected from 36 sites in California in 1947-50, and found it common on carp, mainly on smaller fish from Clear Lake, and absent from all other species. Miller et al. (1973), examined 480 fish in 13 species collected from 13 southern California reservoirs in 1966, and found it on 5 out of 9 carp and absent from all other species. Hensley & Nahhas (1975), examined 545 fish in 28 species collected from the Delta in 1972-73, and found it on nine out of fifty carp, and absent from all other species.

Bauer (1991) states that *D. extensus* was introduced to North America with shipments of carp from Germany, which were first imported to North America in 1831 and to California (directly from Germany) in 1872 (Shebley, 1917; Courtenay et al., 1986). He notes that *D. extensus* was first described from the United States (on carp in Oneida Lake, New York in 1932) and not reported from West Germany until 1966. Haderlie (1950) states in reference to members of the genus *Dactylogyrus* reported from eastern and midwestern states that "it is probable that these parasites are now widespread all over the country, because carp and goldfish which carry the worms have been disseminated widely."

Dactylogyrus extensus has been reported in carp in Wisconsin (1953), Ohio (1954), Michigan (1955), Oklahoma (1957) and northeastern Mexico (1990), and in carp and smallmouth bass *Micropterus dolomieu* in Quebec

(1947) (Hoffman, 1967; Hoffman & Schubert, 1984; Galaviz-Silva et al., 1990). It has also been introduced with carp to Israel (by 1964; Hoffman, 1970), Iraq (Salih et al., 1988) and Indonesia (Buchmann et al., 1993). Kennedy (1994) reported *Dactylogyrus extensus* to be tolerant of a wider range of temperatures than other invasive trematodes in the genus. Hoffman (1970) reported *Dactylogyrus extensus* to be one of ten fish parasites transferred intercontinentally that "have caused great loss to fish culturists and fishermen."

Khawia iowensis Calentine & Ulmer, 1961 [CESTODA]

SYNONYMS: *Caryophyllaeus laticeps* Pall

Khawia iowensis was found in California in three out of fifty carp (*Cyprinus carpio*, native to Eurasia) collected from the Delta in 1972-73 (Hensley & Nahhas, 1975). It was initially recorded in Iowa in 1959-60 in carp and possibly accidental in bigmouth buffalo (*Ictiobus cyprinellus*, in 1 of 15 fish examined), but not in other species examined (Calentine & Ulmer, 1961; Sutherland, 1989). It has also been found in carp in Wisconsin (1963) and Oklahoma (Hoffman, 1967; Hensley & Nahhas, 1975).

Outside of the genus *Khawia*, the only species reported from North America in the 11 other genera in the subfamily Lytocestinae of the family Caryophyllaeidae is the introduced species *Atractolytocestus huronensis* (Calentine & Ulmer, 1961). Of the seven species in *Khawia* (including *iowensis*), five have been reported only from cyprinid fish in Eurasia (Calentine & Ulmer, 1961), and the carp parasite *Khawia sinensis*, native to the Amur Basin, China and Japan, has been introduced to Europe (Hoffman & Schubert, 1984; Bauer, 1991; its 1987 arrival in Great Britain (Kennedy, 1993) was predicted by Chubb et al. (1987) writing in January 1987) and North America (in Oregon in 1975; Williams & Sutherland, 1981). *Khawia iowensis* is clearly a Eurasian tapeworm introduced to North America in carp.

In Iowa the oligochaete *Aulodrilus pigueti* is the intermediate host of *Khawia iowensis* (Sutherland, 1989).

NEMATODA

Philometroides sanguinea (Rudolphi, 1819)

SYNONYMS: *Philometra sanguinea* (Rudolphi, 1819)
Philometra carassii (Ishii, 1934)
Filaria carassii

This Japanese nematode infects blood vessels of the caudal fins of goldfish *Carassius auratus*, and was probably imported to North America via the aquarium trade (Hoffman & Schubert, 1984; Bauer, 1991). It was reported from Canada in 1933 and in Ohio (Hoffman, 1967). Hensley & Nahhas (1975) reported it (as *Philometra carassii*) on 10 of 20 goldfish collected from the the Delta in 1972-73.

Hoffman (1970) reported this nematode to be one of ten parasites transferred intercontinentally that "have caused great loss to fish culturalists and fishermen."

ANNELIDA

Oligochaeta

Branchiura sowerbyi Beddard, 1892 [TUBIFICIDAE]

This oligochaete, native to tropical and subtropical Asia (India, Myanmar (Burma), Java, China, Japan), was first collected in 1892 from the mud of the *Victoria regia* tank in the garden of the Royal Botanic Society in Regent's Park, London. Over the next 30 years it was collected from other warm-water tanks in botanic gardens at Hamburg, Dublin, Kew and Oxford. By the late 1950s it had been found "in the wild" in the Rhone River and elsewhere in southern France, in the Thames River below Reading in water warmed by effluent from a power station, and in unheated waters in the Kennet and Avon Canal and in the Bradford River Avon in England (Mann, 1958). It has also been reported from north and west Africa (Brinkhurst, 1965).

It was first collected in North America in central Ohio in 1930 (Spencer, 1932), and spread to the Great Lakes by 1951 (Mills et al., 1993) and to a total of eighteen states by 1966 (Brinkhurst, 1965; Cole, 1966). In California it was collected from the San Joaquin River in 1950, from the Tuolumne River near Modesto in 1952 (Brinkhurst, 1965), and from the Delta in 1963 (specimen at CASIZ). The California Department of Water Resources has collected it throughout most of the Delta since sampling started in 1977 (from the western Delta upstream to the Mokelumne River, Courtland on the Sacramento River, and Stockton on the San Joaquin River), at densities of up to 823/m² (Markmann, 1986; DWR, 1995). I have found no other records of *Branchiura* on the Pacific coast. *Branchiura*

Hirudinea

Myzobdella moorei (Meyer, 1940)

SYNONYMS: *Illinobdella moorei* (Meyer, 1940)

Haderlie (1950, 1953) reported a leech in this genus (as *Illinobdella*), unidentified to species but probably *moorei*, common on introduced white catfish and brown bullhead collected in Clear Lake in 1949. Miller et al. (1973) found *Myzobdella moorei* on 24 out of 62 channel catfish, 21 of 125 bluegill, 4 of 24 green sunfish, 25 of 185 largemouth bass, 12 of 29 black crappie, 8 of 84 white crappie, and 8 of 18 golden shiner (all introduced fish) collected in southern California reservoirs in 1966. Hensley & Nahhas (1975) found this leech (as *Illinobdella moorei*) on the skin, gills and fins of 24 out of 137 white catfish collected in the Delta in 1972-73. It was probably transported to California from the eastern or midwestern states with introduced catfish or centrarchids. Hoffman (1967) reported it from a wide variety of fish in Connecticut, Tennessee, Ontario, Illinois, Iowa, Minnesota and Wisconsin. and Galaviz-Silva et al. (1990) reported it from channel catfish in northeastern Mexico.

MOLLUSCA: GASTROPODA

Prosobranchia

Busycotypus canaliculatus (Linnaeus, 1758) [MELONGENIDAE]

CHANNELED WHELK

SYNONYMS: *Busycon canaliculatum*
Busycon pyrum

The channeled whelk, a native of the western Atlantic from Massachusetts to Florida, is now by far the largest snail in San Francisco Bay. As discussed by Carlton (1979a), Stohler (1962) stated that the whelk was first collected in the Bay at Alameda in 1948, but specimens from Berkeley at the California Academy of Sciences may have been collected as early as 1938. There are records and frequent observations of the whelk on the eastern shore of the Bay from Alameda and Bay Farm Island to Berkeley, and on the western shore from Belmont Slough to Candlestick Point. One specimen was collected in 1953 from the Tiburon Peninsula in Marin County (Stohler, 1962, Carlton, 1979a, p. 397).

The channeled whelk feeds on bivalves. It produces distinctive strings of egg cases that release crawling (nonplanktonic) snails. Natural dispersal may be achieved by floating egg cases, one string of which was

Copepoda

Acartiella sinensis

This copepod, native to the subtropical to tropical waters of the China coast, was collected in Suisun Bay in 1993, 1994 and 1995. It is found in the vicinity of the entrapment zone and does not extend upstream as far as the eastern Delta (Orsi, 1994, 1995; J. Orsi, pers. comm., 1995). It was probably introduced in ballast water.

Lernaea cyprinacea Linnaeus 1758

ANCHOR WORM

SYNONYMS: *Lernaea carassii* Tidd, 1933
Lernaea elegans Lehigh-Sharpe, 1925
Lernaeocera esocina Hermann, 1783

Described as a "dangerous" and "devastating" parasite, this cosmopolitan copepod infests a wide variety of freshwater fish as well as frog and salamander tadpoles. It was first reported in North America on goldfish in Ohio in 1933 (Haderlie, 1950). Hoffman (1970) and Hoffman & Schubert (1984) described it as having "originated in Asia and spread with the goldfish trade," Bauer (1991) reported it introduced with goldfish "to North America presumably from Japan," and Kennedy (1994) considered it native to the far east. It has been reported from Africa, Europe (Hoffman, 1967, 1970) and Australia (Lever, 1994). In North America it has been reported in Maryland, North Carolina, Ohio, Indiana, Missouri, North and South Dakota, Texas, Oklahoma, Arizona, Washington (Hoffman, 1967) and northeastern Mexico (Galaviz-Silva et al., 1990). Kennedy (1993, 1994) reported that it has been collected on several occasions in Great Britain since the 1960s but has not become established because of low temperatures, and suggested that global warming could facilitate its establishment and spread.

Haderlie (1953) described this copepod (as *Lernaea carassii*) as looking "like small yellowish-green straws sticking out of the skin...the parasites were found all over on certain fish—on the fins, lips, around the eyes, and on the operculum...the cephalothorax gives rise to numerous horns which anchor the parasite to the host...The flesh and skin around the horns of the cephalothorax were often swollen into a soft tumorlike growth, and these growths would be red from the blood that continually oozed out around the neck of the copepod...These parasites are undoubtedly harmful to the fish infected, since they produced numerous bleeding ulcers in the skin."

Haderlie (1950, 1953) collected *Lernaea cyprinacea* in 1947-50 on five native and nine introduced species of fish in California, and on introduced bullfrog tadpoles. Hensley & Nahhas (1975) found it in the Delta on four native and one introduced species of fish in 1972-73. The California hosts of *Lernaea cyprinacea* recorded in these two studies are as follows:

Native:

CYPRINIDAE	Hitch Lavinia <i>exilicauda</i>
	Hardhead <i>Mylopharodon conocephalus</i>
	Sacramento blackfish <i>Orthodon microlepidotus</i>
	Splittail <i>Pogonichthys macrolepidus</i>
	Sacramento squawfish <i>Ptychocheilus grandis</i>
CATOSTOMIDAE	Sacramento sucker <i>Catostomus occidentalis</i>
CENTRARCHIDAE	Sacramento perch <i>Archoplites interruptus</i>

Introduced:

CYPRINIDAE	Carp <i>Cyprinus carpio</i>
ICTALURIDAE	White catfish <i>Ameiurus catus</i>
	Brown bullhead <i>Ameiurus nebulosus</i>
POECILIDAE	Mosquitofish <i>Gambusia affinis</i>
CENTRARCHIDAE	Green sunfish <i>Lepomis cyanellus</i>
	Bluegill <i>Lepomis macrochirus</i>
	Smallmouth bass <i>Micropterus dolomieu</i>
	Largemouth bass <i>Micropterus salmoides</i>
	Black crappie <i>Pomoxis nigromaculatus</i>
AMPHIBIA	Bullfrog <i>Rana catesbeiana</i>

It has also been reported from chinook salmon and rainbow trout in Oregon (reported in 1958; Love & Moser, 1983). Hoffman (1970) reported *Lernaea cyprinacea* to be one of ten parasites transferred intercontinentally that "have caused great loss to fish culturalists and fishermen."

Limnoithona sinensis (Burkhardt, 1912)

SYNONYMS: *Oithona sinensis*

This copepod has been collected from the brackish and fresh waters of the Yangtze River (Changjiang) inland to at least 300 km and from nearby lakes and canals in 1898, in 1906 and prior to 1962. It was collected from the San Francisco Estuary for first time in 1979, by CDFG from the San Joaquin River near Stockton (Ferrari & Orsi, 1984). Herbold & Moyle (1989) suggest that a decline in zooplankton abundance in the Delta prior to 1979 may have facilitated *L. sinensis*' establishment. It has been collected throughout the Delta (where it is more abundant in the San-Joaquin than