Marine Biology (1999) 135: 147–158

S. L. Coles · R. C. DeFelice
L. G. Eldredge · J. T. Carlton

Historical and recent introductions of non-indigenous marine species into Pearl Harbor, Oahu, Hawaiian Islands

Received: 14 April 1998 / Accepted: 22 April 1999

Abstract The benthic organisms and fishes of Pearl Harbor were sampled in 1996, and results were compared with all previous collections and observations from Pearl Harbor assembled from published and unpublished literature and specimens in the Bishop Museum collections. Organisms were designated as native, non-indigenous or cryptogenic (i.e. of uncertain origin). Rates of introductions of non-indigenous and cryptogenic species by decade were estimated from the time of first collections in Pearl Harbor at the turn of the century. Of a total of 419 taxa collected or observed in the 1996 surveys, 95 species (23%) were introduced or cryptogenic, including 12 newly introduced species and 12 new cryptogenic species. Analysis suggests two periods of relatively high introduction rates corresponding to wartime periods. Of the 101 introduced species that have been collected from Pearl Harbor since the beginning of the century, we found 69 species (68%) in 1996. Most of the introduced species collected in 1996 with known geographic origins have distributions extending to the Indo-West Pacific; however, several species are known from the Red Sea and the Caribbean Sea. The only species from these recent introductions that has become abundant and widespread in Hawaii is the small intertidal barnacle *Chthamalus proteus* Dando and Southward, 1980, which was formerly restricted to the Caribbean.

Communicated by M.H. Horn, Fullerton

S.L. Coles (✉) · R.C. DeFelice · L.G. Eldredge
Department of Natural Sciences,
Bishop Museum, 1525 Bernice Street,
Honolulu, Hawaii 96817, USA

Fax: 001(0)808 841 8252
e-mail: slcoles@bishop.bishop.hawaii.org

J.T. Carlton
Maritime Studies Program,
Williams College/Mystic Seaport,
Mystic, Connecticut 06355, USA

Introduction

Non-indigenous marine species have been transported and introduced into new areas for as long as vessels with fouling organisms on their hulls have sailed between oceans. A variety of other vectors for marine invasions, such as transport and culture of shellfish and their associated organisms, connection of formerly separated waterways, and accidental or intentional release of aquarium species, have all contributed in redistributing species among the world's oceans (Ruiz et al. 1997). Since the 1970s, a striking surge of exotic species invasions, largely resulting from shipping activities, has occurred in harbors, ports, and other coastal ecosystems around the world (for reviews see Carlton 1985; Carlton and Geller 1993; Ruiz et al. 1997). The primary vector believed to be most responsible for recent invasions is ballast water carried by ocean-going ships. Ballast water usually contains abundant organisms and, if at-sea ballast-exchange precautions are not taken, these potential invaders may be discharged in harbors where a ship takes on cargo.

The Hawaiian Islands, collectively known as Hawaii, are the most isolated land areas in the world, >4300 km from the nearest major landfalls in North America and the South Pacific, and >6400 km from Japan, the nearest Asian land mass. Prior to the arrival of Europeans in the late eighteenth century, colonization of new species of marine benthic organisms and non-pelagic fishes to Hawaiian waters probably occurred primarily from fouling communities attached to drifting objects or settlement of planktonic larvae that had been transported to Hawaii by ocean currents. Other possible vectors were infrequently arriving Polynesian canoes from the South Pacific or, for small organisms, seabirds.

Development of Hawaii as a crossroads of the Pacific Ocean meant increasing frequency of ship and boat arrivals, and increased probability of introductions of non-indigenous marine species. Carlton (1987) determined that Hawaii is a major potential receiver area, with direct transport routes from six major origins within the Pacific, i.e. four from the western Pacific, one from French Polynesia, and one from western North America. An additional inter-oceanic route to Hawaii may extend from the Atlantic Ocean through the Panama Canal. Carlton estimated that 25 to 28 Western Pacific and two Eastern Pacific coast species have been transported to Hawaii, but surmised that the actual number might be many times greater, especially in the fouling and benthic communities of Kaneohe Bay and Pearl Harbor. Studies are new being conducted in Hawaiian harbors that will provide data to revise Carlton's estimates. This report presents the results of a 1996 study of introduced marine species in Pearl Harbor, Oahu, and compares these findings with all available historical records with the objective of determining whether introductions may be increasing in the harbor.

Pearl Harbor is a large, coastal-plain estuary in central Oahu, Hawaii (see Fig. 1). It is divided into three main lochs (East, Middle and West Lochs) and one smaller loch (Southeast Loch), which are joined together by a main entrance channel that connects with the open ocean. It is one of the three major harbors on the island; the other two serve commercial ship traffic at Honolulu Harbor 10 km to the east, and at Barbers Point 15 km to the west. Traffic in Pearl Harbor is restricted to US Naval ships and a few recreational craft that utilize two small marinas within the harbor. Naval ship activity is concentrated in the Pearl Harbor shipyard and docking areas in Southeast Loch, and many decommissioned ships are anchored in Middle Loch.

The harbor has ~21 km^2 of surface-water area, a mean depth of 8.5 m, and ~58 km of shoreline. The harbor receives five perennial streams and three intermittent streams, draining ≃285 km^2 of watershed, and the discharges from five large springs along the lochs' shoreline. Tidal exchange is small (max. ~0.85 m), and surface-water circulation is primarily offshore and driven by tradewinds, while weak tidal flood and ebb flows of 0.15 to 0.3 m s^{-1} control the movement of bottom water in and out of the harbor. Residence time of water within the harbor has been estimated as up to 6 d for bottom water and 1 to 3 d for surface water (Grovhoug 1992). Water temperature in the harbor varies annually from 23 to 29 °C, and salinities range from 10 to 37‰ (mean 33‰). A power station located along the northeast side of East Loch discharges a maximum 24 m^3 s^{-1} of thermal effluent warmed 5.5 to 7.2 °C from a shoreline outfall (McCain 1975).

Prior to European arrival in the late 18th century and throughout most of the 19th century, the water quality in Pearl Harbor was reportedly high and sedimentation and turbidity low, until damaging land practices in the mid-19th century increased the sediment load reaching the harbor (Sterling and Summers 1978). During the 20th century, the Pearl Harbor Naval Base was developed, and the watershed and shoreline became urbanized. Many habitats of the harbor were drastically altered as shorelines and soft bottoms were converted to docks and other hard surfaces. Before 1911, a sand barrier at the entrance channel of Pearl Harbor limited maximum depth to about 5 m and prohibited access to all but the most shallow-draft vessels. Dredging of the channel to 20 m depth and the opening of Pearl Harbor to Navy ship traffic greatly increased the likelihood of the harbor receiving colonizing immigrant species, and dredging within the harbor to accommodate ships deepened formerly shallow areas. Dredging has continued to be necessary approximately every 10 yr, and was most recently done in 1989. Urbanization of the watershed increased throughout the century, and water quality was highly degraded by the early 1970s (Cox and Gordon 1970).

Despite the poor water-quality conditions, extensive environmental surveys in the 1970s (Evans et al. 1974;

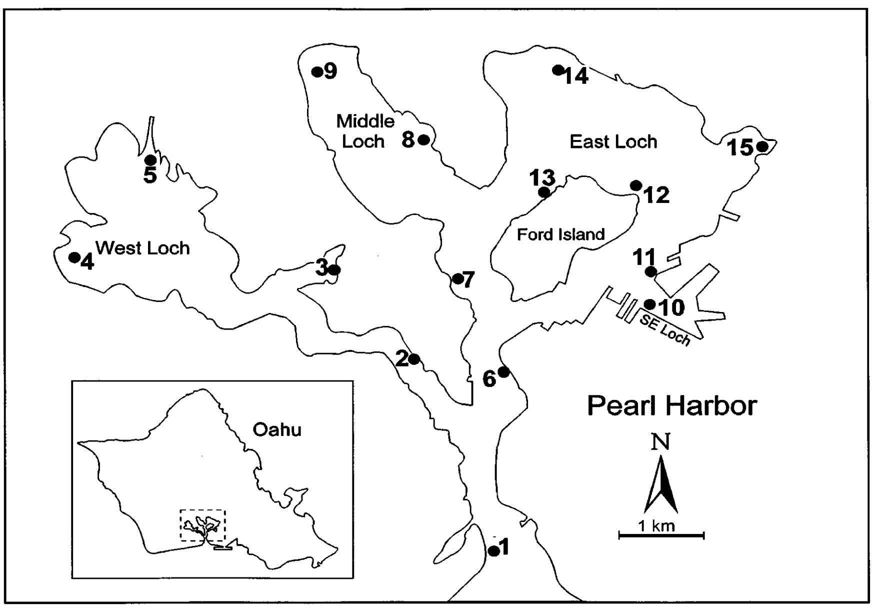

Fig. 1 Locations of sampling stations in Pearl Harbor

McCain 1975) found diverse and abundant biological communities in the harbor. Water quality appears to have improved substantially between the 1970s and the 1990s. In 1975, the Navy instituted shipboard wastewater collection to replace release of vessel wastewater-effluents into the harbor (Grovhoug 1992). Between 1982 and 1984, sewage-effluent discharge ended from all major sources expect one near the harbor entrance. Urbanization of hillsides of the East and Middle Loch watersheds moderated as developments were completed, and better land-management practices during construction helped to alleviate runoff sedimentation. Nevertheless, Secchi disk readings averaged only 2.5 m harbor-wide in 1990, including substantial turbidity from suspended sediments and organic material produced by eutrophic conditions (Grovhoug 1992).

Materials and methods

We sampled and observed benthic biota and fishes between 11 January, and 18 September 1996 at 15 stations (Fig. 1) which included all the principal habitats of Pearl Harbor. Twelve of these stations were selected to coincide with locations throughout the East, Southeast and Middle Lochs previously sampled by Evans et al. (1974) and McCain (1975) in the early 1970s, and three other stations were established in previously unsampled mangrove areas in West Loch. At each station two investigators (SLC and RCD) collected fouling organisms growing on hard surfaces from the intertidal zone to the bottom, which ranged up to 8 m in depth. Organisms and their substrata were collected and retained in a 200 μm-mesh net, and then preserved in 70% alcohol. Sediment-dwelling organisms and their substrata were collected from depths ranging up to 10 m by inserting a 12.5 cm-diam cylinder 15 cm into the sediment and closing off the bottom and top with lids. Preserved samples were wet-sieved in the laboratory through a 500 μm-mesh screen, and a sediment subsample of 10 to 25 cm^3 was retained from each sample for determination of micromollusc populations. Specimens were sorted and identified to species or the lowest practicable taxon. Where identification was uncertain, Voucher specimens were sent to specialists for identification or verification of preliminary identifications (see "Acknowledgements").

Fishes and motile invertebrates were trapped during 2 wk deployments from 12 September to 23 October 1996 in rectangular (79 × 76 × 38 cm) traps, each with one funnel opening and a mesh size of 1.27 cm. Five traps were deployed at one time and were checked weekly. Fishes and invertebrates from the traps were identified on site and released or returned to the laboratory for identification.

We examined all sources of information for previous collections or observations of marine and brackish-water organisms in Pearl Harbor, including published scientific papers, monographs and books, and unpublished environmental reports by and for the US Navy and private organizations. We reviewed the Bishop Museum catalogues of collections of algae, invertebrates and fishes for records of all marine or estuarine organisms collected in Pearl Harbor or near its entrance. The species name, year of collection, collector's name, and collector's notes were assembled into a Bishop Museum database which was combined with databases from the literature search and from the present study. After corrections for synonymies and nomenclatural changes, we assembled a master list that gave the first record of each taxon in Pearl Harbor and all subsequent reports of collections or observations.

Species were designed as introduced (non-indigenous) based on criteria described in Chapman (1988) and Chapman and Carlton (1991). These criteria include new appearances in local regions, association with human mechanisms of dispersal (e.g. fouling on ship bottoms), association with other introduced species, restriction to artificial or disturbed habitats (e.g. harbors), and widespread, disjunct geographic distributions. Species that were not demonstrably introduced or native were considered to be cryptogenic [of undetermined origin, sensu Carlton (1996)]. The probable origins or previously known geographic ranges of the introduced species occurring in Pearl Harbor in 1996 were derived from the general literature and from Carlton and Eldredge (1999).

Results

A total of 1123 taxa have been reported by all sources (including the present study) for Pearl Harbor, with 1091 of these reports having collection dates. These totals include unverified and unvouchered species reports as well as taxa not identified to species. Of the 1123 reported taxa, 844 were identified to the species level. In 1996 we collected or observed a total of 419 taxa (36 algae, 1 spermatophyte, 323 invertebrate and 59 fish) from the 15 stations sampled, with 355 taxa (85%) identified to species. This is the highest number of taxa reported for any single Pearl Harbor study [≃8% more than the 388 taxa reported by the previous most comprehensive survey of the harbor by Evans et al. 1974]. The 64 taxa not identified to species were primarily algae (18 taxa), polychaetes (16 taxa) and micro-molluscs (10 taxa). In the present study, 173 are new species reports for Pearl Harbor, and 35 of these are new reports for Hawaii. Listings of taxa collected and previously reported are available on a Bishop Museum website (http://www.bishop.hawaii.org/bishop/invert/phlegacy.html).

Ninety-five species, or ~23% of the 419 taxa collected or observed in 1996, were introduced or cryptogenic (Table 1). One of these, one was an introduced alga (*Acanthophora spicifera*) and four were introduced fishes (*Poecilia* cf. *latipinna*, *Oreochromis mossambicus*, *Sarotherodon melanotheron*, and *Lutjanus fulvus*). The rest were invertebrates, with only one non-indigenous species (*Crepidula aculeata*) occurring in the sediment fauna. This species was also common in the fouling community, which included all the remaining 89 introduced or cryptogenic species. Introduced or cryptogenic sponges, polychaetes, bryozoans and tunicates sometimes covered nearly 100% of available surfaces in many areas of the harbor. Two species of introduced sponges *Mycale* (*Carmia*) *cecilia* (de Laubenfels, 1936) and *Suberites zeteki* (de Laubenfels, 1936) were so abundant at the power-station outfall in East Loch that they form a virtual sponge reef. West Loch areas receiving highly turbid runoff and sedimentation were dominated by introduced oysters [*Crassostrea virginica* (Gmelin, 1791)], wherever hard substrata were available for settlement and growth.

Of the 95 introduced or cryptogenic species found in 1996, 57 were species previously reported in Hawaii and considered introduced, 14 were previously reported and cryptogenic, 12 were new reports and introduced, and 12 were new reports and cryptogenic (Table 1). Two non-

Table 1 Non-indigenous and cryptogenic species collected or observed in Pearl Harbor in 1996 (* newly introduced non-indigenous species; *PR* previously reported; *NR* new report; *I* introduced; *C* cryptogenic; *First PH* year first collected in Pearl Harbor; *BPBM*, *USNM* Bishop Museum and US National Museum catalogue nos.; *Org* origin or range; *WIP* Western Indo-Pacific; *IP* Indo-Pacific; *EP* Eastern Pacific; *RS* Red Sea; *WA* Western Atlantic; *EA* Eastern Atlantic and Mediterranean, *CA* Caribbean; *WW* worldwide; – insufficient information available)

Taxa	Status	First PH	Source and/or comment	Origin/previous range and status authority	Org
Rhodophyta					
Rhodomelaceae					
Acanthophora spicifera	PR, I	1952	Introduced into Pearl Harbor on barge fouling	Guam–Australia: Doty (1961)	WIP
Porifera					
Demospongia					
Heteropia glomerosa	NR, C	1996	Present study	} Kelly-Borges and DeFelice (unpublished data)	–
Hyatella intestinalis	NR, C	1996	Present study	}	
Dysidea cf. *avara*	PR, C	1996	Present study; 1948 in Kaneohe Bay: de Laubenfels (1950)	}	
Dysidea cf. *arenaria*	NR, C	1996	Present study	}	
Callyspongia cf. *diffusa*	PR, C	1947	de Laubenfels (1957)	}	
*Gelliodes fibrosa**	NR, I	1996	Present study	Philippines: Kelly-Borges and DeFelice (unpublished data)	WIP
*Sigmadocia caerulea**	NR, I	1996	Present study	Caribbean: Kelly-Borges and DeFelice (unpublished data)	CA
Biemna fistulosa	NR, C	1996	Present study	Kelly-Borges and DeFelice (unpublished data)	–
Mycale (*Aegogropila*) *armata*	NR, C	1996	Present study	Kelly-Borges and DeFelice (unpublished data)	–
Mycale (*Carmia*) *cecilia*	PR, I	1947	de Laubenfels (1950)	Caribbean: Kelly-Borges and DeFelice (unpublished data)	CA
Zygomycale parishii	PR, I	1947	de Laubenfels (1950)	Kelly-Borges and DeFelice (unpublished data)	IP
Tedania reticulata	NR, C	1996	Present study	Kelly-Borges and DeFelice (unpublished data)	–
Halichondria melanadocia	PR, I	1993	Brock (unpublished report); 1967 in Kaneohe Bay (Bergquist 1967)	Caribbean	CA
Topsentia sp.	NR, C	1996	Present study	Kelly-Borges and DeFelice (unpublished data)	–
Suberites zeteki	PR, I	1947	de Laubenfels (1957)	Panama–Caribbean: Kelly-Borges and DeFelice (unpublished data)	CA
Echinodictyum asperum	NR, C	1996	Present study	Kelly-Borges and DeFelice (unpublished data)	–
Cliona sp.	PR, C	1947	as *C. vastifica* (de Laubenfels 1957)	Kelly-Borges and DeFelice (unpublished data)	–
Cnidaria					
Hydrozoa					
Halocordyle disticha	PR, I	1929	BPBM D-183	European Atlantic, worldwide: Cooke (1977), Carlton and Eldredge (1999)	EA
Anthozoa					
Carijoa (= *Telesto*) *riisei*	PR, I	1972	BPBM D-454	Florida–Brazil: Bayer (1961), Carlton and Eldredge (1999)	CA
Annelida					
Polychaeta					
Chaetopterus sp.	PR, C	1976	Grovhoug and Rastetter (1980) as *C. variopedatus*	} Carlton and Eldredge (1999)	–
Eulalia sanguinea	PR, C	1966	Hartmann (1966)	}	
Branchiomma nigromaculata	PR, C	1966	Hartmann (1966)	}	
Sabellastarte sanctijosephi	PR, C	1976	Grovhoug and Rastetter (1980)	}	

Table 1 (continued)

Taxa	Status	First PH	Source and/or comment	Origin/previous range and status authority	Org
Hydroides dirampha	PR, I	1929	BPBM D-1083 as *H. lunulifera*	Tropical and temperate worldwide: Bailey-Brock and Hartman (1987)	WW
Hydroides elegans	PR, I	1929	BPBM D-1101 as *H. norvegica*	Worldwide: Bailey-Brock and Hartman (1987)	WW
Pomatoleios kraussii	PR, I	1976	Grovhoug and Rastetter (1980)	Tropical Indo-West Pacific: Bailey-Brock and Hartman (1987)	WIP
Salmacina dysteri	PR, I	1972	Long (1972)	Tropical worldwide: Bailey-Brock and Hartman (1987)	WIP
Serpula sp.	PR, C	1938	Straughan (1969) as *S. vermicularis*	Carlton and Eldredge (1999)	–
Spinther japonicus	PR, C	1976	Grovhoug and Rastetter (1980)	Carlton and Eldredge (1999)	–
Mollusca					
Gastropoda					
Diodora ruppelli	PR, I	1962	Kay (1979)	Tropical Indo-West Pacific–Red Sea (Kay 1979)	WIP
Crepidula aculeata	PR, I	1915	BPBM MO-231366	Worldwide: Kay (1979)	WW
Crucibulum spinosum	PR, I	1950	1946 in Honolulu Harbor (Edmondson 1946)	Worldwide: Kay (1979)	WW
Vermetus alii	PR, I	1973	Evans et al. (1974)	Florida: M.G. Hadfield (personal communication in Carlton and Eldredge 1999)	WA
Hinemoa indica	PR, C	1973	Evans et al. (1974)	Carlton and Eldredge (1999)	–
Bivalvia					–
Anomia nobilis	PR, C	1912	BPBM MO-68170	Carlton and Eldredge (1999)	
Crassostrea virginica	PR, I	1866	Kay (1979)	Eastern N. America: Carlton and Eldredge (1999)	WA
*Saccostrea cucullata**	NR, I	1996	*O. cucullata* planted in Kalihi in 1928/1929	Australia: Edmondson and Wilson (1940)	WIP
*Chama ?elatensis**	NR, I	1996	Present study	Red Sea: Paulay (personal communication)	RS
Chama fibula	PR, I	1920	Dall et al. (1938)	Philippines–Australia: Carlton and Eldredge (1999)	WIP
Chama lazarus	PR, I	1950	USNM 699558	East Africa–Tonga: Paulay (1996)	IP
Chama pacifica	PR, I	1950	USNM 699565	Thailand–Line Islands: Paulay (1996)	IP –
Abra sp.*	NR, I	1996	Present study	Unknown	
Venerupis (*Ruditapes*) *philippinarum*	PR, I	1918	Dall et al. (1938)	Japan, Indo-West to East Pacific: Carlton and Eldredge (1999)	WIP
*Sphenia ?coreanica**	NR, I	1996	Present study	Unknown	–
Martesia striata	PR, I	1920	Dall et al. (1938)	Throughout Atlantic and Pacific: Kay (1979)	WW
Teredo bartschi	PR, I	1935	Edmondson (1942)	Worldwide (Kay 1979)	WW
Arthropoda					
Pycnogonida					
*Pigrogromitus timsanus**	NR, I	1996	Present study	C.A. Child (personal communication)	–
Cirrepedia					
Balanus amphitrite amphitrite	PR, I	1913	Pilsbry (1928)	Red Sea, worldwide: Carlton and Eldredge (1999)	RS
Balanus ebumeus	PR, I	1929	BPBM Spec. B-271	Western N. Atlantic, worldwide: Carlton and Eldredge (1999)	WA
Balanus reticulatus	PR, I	1915	Henry and McLaughlin (1975)	Worldwide: Carlton and Eldredge (1999)	WW
*Chthamalus proteus**	NR, I	1996	Present study	Caribbean: Southward et al. (1998)	CA

(Continued overleaf)

Table 1 (continued)

Taxa	Status	First PH	Source and/or comment	Origin/previous range and status authority	Org
Tanaidacea				–	–
Leptochelia dubia	PR, C	1973	McCain (1975)		
*Parapseudes pedispinus**	NR, I	1996	Present study	Southern California–Equador: Muir (1997)	EP
Isopoda					
Mesanthura sp.	NR, C	1996	Present study	–	–
Amphipoda					
Paraleucothoe ?flindersi	NR, C	1996	Present study	Australia: Barnard and Karaman (1991)	WIP
Limnoria tripunctata	PR, I	1973	1945 in Honolulu Harbor (BPBM S-5722)	Worldwide: Muir (personal communication)	WW
Exosphaeroma sp.	NR, C	1996	Present study	–	–
Corophium ascherusicum	PR, I	1973	1943 at Waikiki (Barnard 1955)	Tropical and temperate worldwide: Barnard (1971)	WW
Corophium baconi	PR, I	1973	1967 in Kaneohe Bay (Barnard 1970)	Bering Sea–Peru: Barnard (1970)	EP
Corophium insidiosum	PR, I	1978	1959 at Hilo (Barnard 1970)	North Atlantic: Carlton and Eldredge (1999)	A
Ericthonius brasiliensis	PR, I	1938	Barnard (1955)	Tropical and temperate worldwide: Muir (personal communication, Carlton and Eldredge 1999)	WW
Grandidierella bispinosa	NR, C	1996	Present study	Muir (1997)	–
*Grandidierella japonica**	NR, I	1996	Muir (1997), see also Carlton and Eldredge (1999)	Japan: Carlton and Eldredge (1999)	WIP
Elasmopus rapax	PR, I	1948	1937 in Kaneohe Bay (Barnard 1955)	Tropical worldwide: Barnard (1970)	WW
Podocerus brasiliensis	PR, I	1938	1935 in Kaneohe Bay (Barnard 1955)	Tropical and temperate worldwide: Muir (personal communication)	WW
Stenothoe gallensis	PR, I	1937	1935 in Kaneohe Bay (Barnard 1955)	Tropical worldwide: Carlton and Eldredge (1999)	WW
Stenothoe valida	PR, C	1978	1967 on east coast Oahu (Barnard 1970)	Carlton and Eldredge (1999)	WA
Decapoda					
Scylla serrata	PR, I	1972	Introduced to Hawaii in 1932 (Brock 1960)	Guam, Red Sea-Tahiti: Brock (1960)	IP
*Nanosesarma minutum**	NR, I	1996	Present study	East Africa–Thailand: Carlton and Eldredge (1999)	WIP
Panopeus lacustris (= *P. herbstii*)	PR, I	1947	Edmondson (1962)	Tropical Atlantic: Carlton and Eldredge (1999)	A
Panopeus pacificus	PR, I	1929	BPBM S-3435	Unknown: Carlton and Eldredge (1999)	–
Gonodactylus aloha	PR, I	1973	1963 at Waikiki (Kinzie 1968) as *G. falcatus*	Eastern Pacific-Philippines: Kinzie (1968)	WIP
Bryozoa					
Amathia distans	PR, I	1948	1935 in Kaneohe Bay (Edmondson and Ingram 1939)	Tropical worldwide: Carlton and Eldredge (1999)	WW
Aetea truncata	PR, I	1972	1935 in Kaneohe Bay (Edmondson and Ingram 1939)	Unknown: Carlton and Eldredge (1999)	–
Bugula neritina	PR, I	1921	BPBM K-235	Tropical worldwide: Soule and Soule (1967)	WW
Bugula stolonifera	PR, I	1940	BPBM K-223, 226, 230	Tropical worldwide: Gordon and Mawatari (1992)	WW
Savignyella lafontii	PR, I	1972	1935 in Kaneohe Bay (Edmondson and Ingram 1939)	Tropical Atlantic: Carlton and Eldredge (1999)	A
Schizoporella errata	PR, I	1973	Possibly pre-1933 (Edmondson 1933)	Worldwide: Carlton and Eldredge (1999)	WW
Schizoporella unicomis	PR, I	1935	Ingram (1937)	Northwest Pacific: Carlton and Eldredge (1999)	EP

Table 1 (continued)

Taxa	Status	First PH	Source and/or comment	Origin/previous range and status authority	Org
Waterispora edmondsoni	PR, I	1972	1966 in Ala Wai (Soule and Soule 1967)	Tropical–subtropical Pacific: Carlton and Eldredge (1999)	IP
Chordata					
Ascidiacea					
Ascidia sydneiensis	PR, I	1976	BPBM Y-244	Tropical worldwide: Abbott et al. (1997)	WW
Ascidia sp. B	PR, I	1996	Abbott et al. (1997), date unspecified	Tropical Western Pacific: Abbott et al. (1997)	WW
Botryllus (= *Botrylloides*) sp./spp.	PR, I	1973	McCain (1975)	Abbott et al. (1997), Lambert (personal communication)-	–
Herdmania momus	PR, I	1972	Long (1972)	Tropical worldwide: Abbott et al. (1997)	WW
Microcosmus exasperatus	PR, I	1996	Abbott et al. (1997), date unspecified	Tropical worldwide: Abbott et al. (1997)	WW
Phallusia nigra	PR, I	1985	Hurlbut (1990)	Worldwide: Abbott et al. (1997)	WW
Polyandrocarpa sp.	PR, I	1996	Present study	Lambert (personal communication)	–
Polyclinum constellatum	PR, C	1973	McCain (1975)	Tropical worldwide: Monniot and Monniot (1997)	WW
Symplegma brakenhielmi (= *S. oceania*)	PR, I	1975	Grovhoug (1976) at *S. connectans*	Tropical worldwide: Monniot and Monniot (1997), Lambert and Lambert (1998), Carlton and Eldredge (1999)	WW
*Symplegma reptans**	NR, I	1996	Present study	Japan: Lambert and Lambert (1998)	WIP
Actinopterygii					
Poecilia cf. *latipinna*	PR, I	1905	Introduced in 1905 in Pearl Harbor	Eastern North America: Brock (1960), Randall (1987)	WA
Oreochromis mossambicus	PR, I	1973	Introduced in 1952 around Oahu	East Africa, tropical worldwide: Brock (1960), Randall (1987)	WIP
Sarotherodon melanotheron	PR, I	1987	Introduced in 1970 around Oahu	West Africa, tropical worldwide: Maciolek (1984), Randall (1987)	WIP
Lutjanus fulvus	PR, I	1973	Introduced in 1956 and 1959 in Kaneohe Bay	Tropical Indo-Pacific: Maciolek (1984), Randall (1987)	IP

indigenous species were previously first reported in the 1990s (Brock 1994), one of which (*Halichondria melanodocia*) was also found in the present study (Table 1). Introduced species newly reported here include two sponges [*Gelloides fibrosa* (Wilson, 1925) and *Sigmadosia caerulea* Hechtel, 1965], four bivalve molluscs [*Saccostrea cucullata* (Born, 1778), *Chama ?elatensis* Delsaerdt, 1896, *Abra* sp. and *Sphenia ?coreanica* Habe, 1951], one pycnogonid (*Pigrogromitus timsanus* Calman, 1927), four crustaceans [*Chthamalus proteus* Darbo and Southward, 1980 *Parapseudes pedispinus* Boone, 1923, *Grandidierella japonica* Stephenson, 1938 and *Nanosesarma minutum* (De Man, 1887)], and one colonial tunicate [*Symplegma reptans* (Oka, 1927)].

The introduced sponges *Gelliodes fibrosa* and *Sigmadocia caerulea* were collected for the first time in Hawaii in this survey. *G. fibrosa* was previously known only from the Philippines. It is now established in the harbors of Oahu, Kauai and Maui, but has not been found on the island of Hawaii (Kelly-Borges and DeFelice unpublished data). In Pearl Harbor, it was abundant on the hull of a floating drydock brought from the Philippines in 1992. *S. caerulea* was previously known only from the Caribbean, but is now common on artificial surfaces of all harbors on the main Hawaiian Islands and Midway Atoll (Kelly-Borges and DeFelice personal communication). It is unlikely that these large, conspicuous sponges could have been overlooked during the last survey of Hawaiian sponges (Bergquist 1967).

The introduced oyster *Saccostrea cucullata* occurred throughout the harbor. Although a new report for Pearl Harbor, this population may be the relict of Australian oysters (reported as *Ostrea cucullata*) that were planted in Kalihi and Kaneohe in 1928 but reported not to have survived (Edmondson and Wilson 1940; Brock 1952). The spiny rock oyster *Chama ?elatensis*, previously unknown outside the Red Sea (Paulay personal communication), was abundant on the hull of the floating drydock brought from the Philippines in 1992, and single specimens were found at three other stations. Only a single specimen of *Abra* sp. was found. The bivalve *Sphenia ?coreanica* is new record for Hawaii and was abundant at many stations.

The introduced pycnogonid *Pigrogromitus timsanus*, previously found elsewhere throughout the tropics, occurred only in the area of the thermal outfall. The most abundant newly introduced species in Pearl Harbor was the barnacle *Chthamalus proteus*, which dominated the intertidal zone on hard substrata at 9 of the 15 stations. This species is native to the Caribbean, and it had not previously been reported in the Pacific (Southward et al. 1998).

Only two newly introduced peracarid species were detected in the present study. The tanaid *Parapseudes pedispinis* was previously reported to range from California to Ecuador (Muir 1997). Chapman and Dorman (1975) previously reported the gammarid amphipod *Grandidierella japonica* as a species synonymous with *Neomicrodeutopus makena* (Barnard, 1970). However, Muir considers the specimens that he identified from the present study as *G. japonica* to show clear differences from the holotype of *N. makena*, and thus to be a first report for Hawaii.

Another newly introduced crustacean was *Nanosesarma minutum*, a small grapsid crap previously reported from East Africa to Japan (Davie 1998). This species was moderately abundant at nearshore stations of Middle and East Loch and at the channel entrance to Middle Loch.

The newly introduced ascidian *Symplegma reptans* is a Japanese species that has recently become abundant in Mission Bay, San Diego, and is present at Long Beach Harbor, California (Lambert and Lambert 1998). This species occurred in Pearl Harbor only on the hull of the floating drydock brought from the Philippines.

The numbers of non-indigenous and cryptogenic species that were present in Pearl Harbor in 1996 are shown by decade of their first appearance in Fig. 2. This presentation of the data would suggest that introductions increased dramatically in the 1970s and 1990s; however, total numbers of species newly reported in Pearl Harbor also increased in the 1970s and 1990s (Fig. 3), probably due to increased sampling from numerous studies (Evans et al. 1974; McCain 1975; Grovhoug 1979; Grovhoug and Rastetter 1980; Brock 1994; Coles et al. 1997). Plotting the ratio of non-indigenous plus cryptogenic species relative to total new-taxa reports by decade (Fig. 3) indicates that species introductions were highest during the 1940s decade of World War II (1941 to 1945), and during the 1910s, coinciding with opening of the entrance channel (1911) and World War I (1917 to 1918). The ratio of non-indigenous plus cryptogenic species to total new reports during those decades were more than twice the ratio in any other decade, and no increases in species introductions are apparent for recent decades from the available data. Elimination of cryptogenic species from this analysis would further reduce the ratio values for the 1970s and 1990s in comparison with other decades.

The results were analyzed for the percentages of non-indigenous species previously reported in Pearl Harbor that were still present in 1996. Of the 101 non-indigenous species that have been reported since 1899, we observed or collected a total of 69 (68%). By decade, non-indigenous species found in 1996 ranged from 100% for the six species first detected in the 1910s to a low of 33% for the three species first found in the 1960s. For the remaining decades ≥50% of the non-indigenous species still occurred in Pearl Harbor in 1996. These are conservative estimates of persistence, because some previously reported but rare species may still occur in the harbor that may not have been detected in the 1996 surveys.

The percentages of the species by origin or range for seven geographic areas in the Pacific and the Atlantic were estimated. Most of the species (36%) were of indeterminate origin, occurring in temperate or tropical waters worldwide. Of those species for which an origin or previous range can be designated, most are known

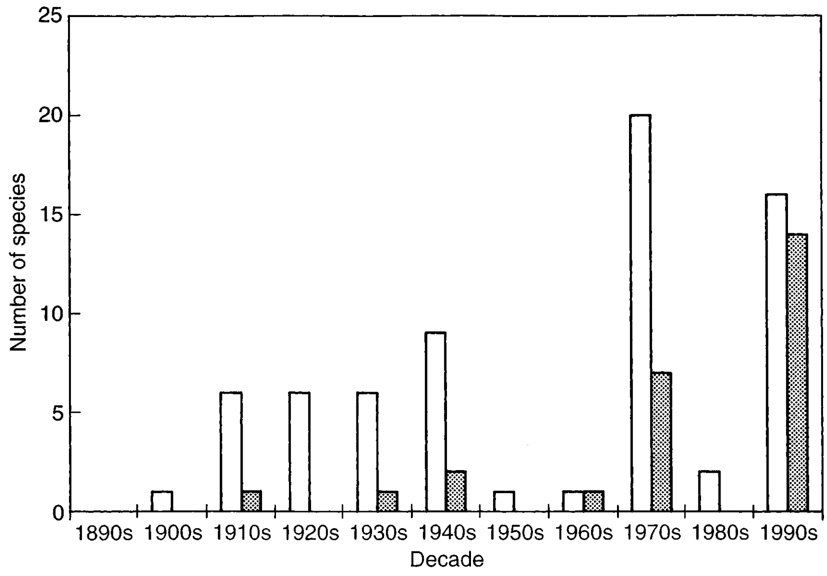

Fig. 2 First reports (recorded by decade) from 1890 to 1996 of introduced and cryptogenic species in Pearl Harbor in 1996 (*Gray bars* cryptogenic species; *open bars* non-indigenous species)

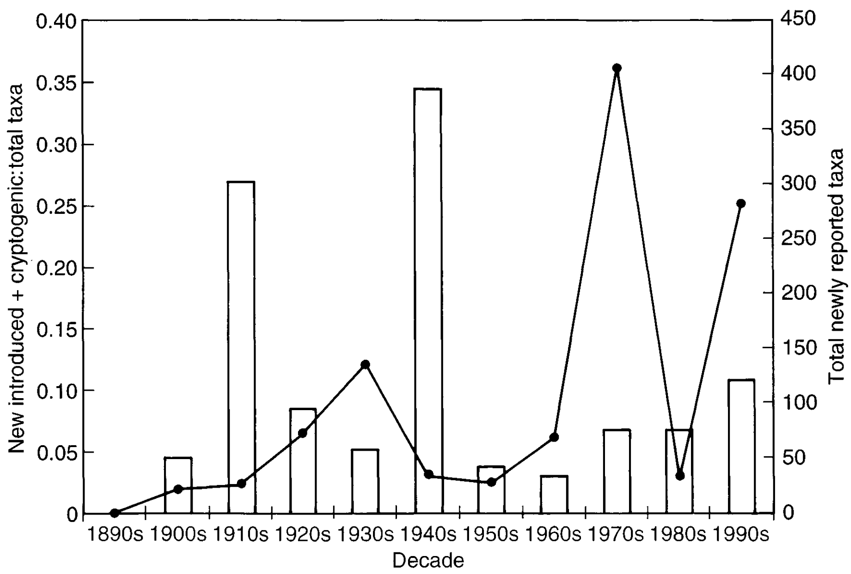

Fig. 3 Ratio of new reports of non-indigenous + cryptogenic species to total newly reported taxa (*open bars*) and total newly reported taxa (*line*) (recorded by decade) in Pearl Harbor, 1890 to 1996

from the western Indo-Pacific (23%) and the general Indo-Pacific (9%), with additional fractions from the Eastern Pacific (5%) and the Red Sea (3%), totalling 40% for the Pacific region. Twenty four percent of the introduced species come from the Atlantic Ocean, with nearly half of these coming from the Caribbean (11% of total).

Discussion

Pearl Harbor has received introduced species since at least 1866, when the first attempts at culturing eastern oysters (*Crassostrea virginica*) were made in the harbor. This was the only species, introduced or otherwise, reported in Pearl Harbor until collecting began in 1899. Reported non-indigenous species in the harbor increased from 1 species in the 1900s to 6 species in the 1910s decade, after the completion of the ship channel in 1911 enabled entry of ocean-going vessels into the harbor and provided the opportunity for the release of non-indigenous marine organisms. An even greater increase in relative non-indigenous introductions is suggested during the 1940s, coinciding with and following World War II. Quantitative information on Navy ship traffic in the harbor that could enable statistical correlation with marine introduction rates is not available. However, Pearl Harbor was the major focus for the massive mobilization of naval vessels that occurred for the World War II Pacific theater, enabling marine organism transport and introduction into the harbor. Moreover, numerous on-site reports exist of newly introduced species sampled from Pearl Harbor vessels following the end of the war or appearing in the Hawaiian marine fauna shortly thereafter (de Laubenfels 1950, 1951; Edmondson 1951, 1962; Doty 1961).

The historical results indicate that presentation of introductions as absolute numbers with time (Fig. 2) may result in potentially misleading interpretations of accelerating rates of introductions, unless the data is normalized in terms of some indicator of sampling effort. Without information on the actual effort involved, total new species reports may provide a means of evaluating rates of species introduction (Fig. 3), if there are sufficient historical data available. Even with 15% of the taxa collected in our survey not identified to species, the low ratio of introductions to total reports in recent decades suggests that introductions into Pearl Harbor have not been accelerating, even though the absolute numbers of new non-indigenous and cryptogenic species in the 1970s and 1990s were ~4 to 30 times greater than in any other decade. The data suggest that a background rate of 5–10% of total new introduced species reports has applied in Pearl Harbor throughout this century, except during decades of high wartime activity. However, this pattern of species introductions may pertain solely to the special circumstance of a restricted military harbor receiving no commercial traffic.

Data interpretation is further complicated by the fact that an introduced organism may have been present in Pear Harbor or Hawaii for some time before it was detected by a taxonomic specialist. For example, 5 of the 7 non-indigenous and cryptogenic species first found in the 1910s were molluscs collected by various malacologists and identified in Dall et al. (1938), and 5 of the 11 non-indigenous or cryptogenic species first noted in the 1940s were sponges reported by de Laubenfels (1950, 1957) from the first collections that had been made in Hawaii. This indicates that, along with sampling effort, the amount of new attention given to any taxonomic group can be a significant factor influencing an historical analysis of non-indigenous species introductions. While we note this potential bias, we include the reports of fouling sponges in Pearl Harbor for the post-World War II period because of the volume of shipping that occurred in the 1940s, and thus the likelihood that most, if not all, these species were introduced at that time.

The total of 69 non-indigenous and 26 cryptogenic species found in this study is low compared to those reported in other studies of various temperate areas where aquatic invasions have been evaluated; however, these latter studies involved much larger bodies of water than Pearl Harbor. San Francisco Bay, probably the area most disturbed by marine invasions, had 234 non-indigenous and at least 125 cryptogenic species (Cohen and Carlton 1995, 1988) by 1995. Numbers of non-indigenous species in other temperate regions summarized by Ruiz et al. (1997) are Coos Bay Oregon (60), temperate Australian waters (70), Chesapeake Bay (116), the Great Lakes (212) and the Mediterranean Sea (> 240). These apparently greater occurrences of non-indigenous species may be related to a number of factors, including sampling area and effort, differences in habitat disturbance, resistance of the native marine populations to invasion, frequency of inoculation by invading populations, and difficulties in resolving the species-level taxonomy of tropical and subtropical organisms. Given the isolation of Hawaii from potential donor areas, the number of marine introductions that have occurred in Pearl Harbor is still substantial. By contrast, a survey of 12 harbor areas from Brisbane, northward in tropical Queensland, Australia (Hilliard et al. 1997), found a total of only 15 non-indigenous and 15 cryptogenic species, none of which seriously impacted local marine communities.

Although previously-introduced non-indigenous invertebrates dominate certain areas of the harbor and are common in harbors elsewhere in Hawaii, most of these species have been in Hawaii for 50 to 70 yr and are generally restricted to artificial surfaces in areas of high nutrient and turbidity. One recently introduced species has proliferated and become widespread throughout the tropical north Pacific. The intertidal barnacle *Chthamalus proteus* is now abundant in harbors on the islands of Hawaii, Maui, and Kauai (DeFelice personal observations). It also occurs at Midway Atoll, 1750 km northwest of Oahu (DeFelice et al. 1998), and has recently been reported from Guam (Southward et al. 1998). We recently sampled it from a barge which is towed monthly between Honolulu, Johnston Island Kwajalein Atoll. This barnacle's dramatic spread demonstrates the rapid rate at which a non-indigenous species can successfully invade widely distributed new areas.

The non-indigenous alga *Acanthophora spicifera*, believed to have been introduced to Pearl Harbor as fouling on a barge towed from Guam in 1950 (Doty 1961), is now abundant on most of the main Hawaiian Islands, and is considered a nuisance-species that suppresses the growth of native algae (Russell 1992). The four non-indigenous fishes in Pearl Harbor were intentional introductions, either early in this century to suppress mosquito larvae, in the 1950s for fishes enhancement, or in the 1970s for aquaculture. The tilapia (*Oreochromis mossambica* and *Sarotherodon melanotheron*) especially are considered nuisances that have penetrated Hawaiian streams and compete with native fishes.

At least 68% of the non-indigenous species introduced into Pearl Harbor in this century were still present in 1996, and many were dominant members of the fouling community. The 1911 to 1920 decade had the highest proportion of first reports of non-indigenous introductions still found in 1996, indicating no general decline in the persistence of introduced organisms with time. This implies that successfully introduced non-indigenous species are likely to become permanent components of the harbor's biotic community.

Our analysis suggests that nearly twice as many non-indigenous species in Pearl Harbor originate from the Pacific than from the Atlantic. The western Indo-Pacific accounted for the most species, more than double those from the Caribbean, the region with the next highest numbers. This is a predictable consequence of movements of military ships to and from tropical areas throughout the century, and of nonmilitary ships, predominantly fishing boats, from Asia and the western Pacific (Carlton 1987; Carlton et al. 1995).

Some of the more vigorous vectors of introductions in other world ports may operate at a relatively lower scale in Pearl Harbor and other Hawaiian ports. Although early introductions involved organisms for commercial culture (i.e. *Crassostrea virginica* in 1866, 1893 and 1895; *Venerupis* (*Ruditapes*) *philippinarum* in 1918 to 1920; *Crassostrea gigas* in 1938), no imports of commercial shellfish are known to have occurred in Pearl Harbor in the least 60 yr. The total quantities of ballast water carried to the Hawaiian Islands are low compared to other port areas. The major ship traffic in the Hawaiian Islands consists of loaded container ships and inbound petroleum tankers, neither of which carry the ≥25 000 metric tons of ballast water utilized by bulk carriers. A 1991 study (Carlton et al. 1995) estimated total annual ballast for Honolulu Harbor to be only ~79 000 metric tons, compared to nearly 13.5 million metric tons for New Orleans, the highest for the USA. For Pearl Harbor, no information is available on the amounts of ballast water released, but virtually all traffic in and out of Pearl Harbor comprises military ships, which generally carry far less ballast water than commercial vessels. Therefore, hull- and sea-chest fouling communities may play a role equal or exceeding that of ballast water, depending on vessel type, length of service out of drydock, and source region.

Our observations suggest that conditions in Pearl Harbor have become more favorable to native organisms formerly excluded from the harbor. Few data are available to verify quantitatively the general improvement of water quality in the harbor since comprehensive surveys were last made in the early 1970s. However, five species of reef corals were found in this study (Coles 1999), some of them occurring well into the harbor. In contrast, Grovhoug (*in* Evans et al. 1974) noted 25 yr ago that "stony corals were conspicuously absent from all biostations in Pearl Harbor..." including a location near the harbor entrance where the present study found three coral species. Two coral species occurred well into the harbor, with the distribution of one extending to the shoreline at the head of East Loch. We observed improved water clarity compared to 20 yr ago, and many sources of pollution have abated since the 1970s (Grovhoug 1992). How improved water quality may have affected the ability of non-indigenous species to become established in the harbor is unknown, but competition with native organisms not previously found in the harbor may be an important factor.

Acknowledgements This study was conducted with the support of Department of Defense Legacy Project No. 106 to the Bernice P. Bishop Museum. The assistance of the management and staffs of the Library and Department of Natural Sciences at Bishop Museum is much appreciated. Special thanks go to R.L. Pyle, who developed the database, A. Suzumoto, who managed the specimen collections, and R. Cowie, who reviewed the manuscript. Helpful comments of the manuscript were provided by M. Strathmann, M. Wonham and two anonymous referees. Taxonomic expertise for identifying organisms was provided by the following individuals, and their efforts and contributions to this project are gratefully acknowledged. Algae: Dr. I. Abbott, Bishop Museum and University of Hawaii; sponges: Dr. M. Kelly-Borges, UNITEC Institute of Technology, Auckland; polychaetes: Dr. J. Bailey-Brock, University of Hawaii; gastropods: Dr. R. Cowie and Ms. R. Kawamoto, Bishop Museum; bivalves: Dr. G. Paulay, University of Guam Marine Laboratory, and Dr. E. Coan, Santa Barbara Museum of Natural History; micromolluscs: Dr. E.A. Kay, University of Hawaii; pycnogonids: Dr. C.A. Child, Smithsonian Institution; amphipods, isopods and tanaids: Dr. D. Muir, Bishop Museum (Affiliate); isopods: Dr. R. Brusca, College of Charleston; barnacles: Dr. W. Newman, Scripps Institution of Oceanography; decapods: Dr. P. Ng, University of Singapore; ascidians: Dr. G. Lambert, California State University at Fullerton; fishes: Mr. A. Suzumoto, Bishop Museum.

References

Abbott DP, Newberry AT, Morris KM (1997) Reef and shore fauna of Hawaii. Section 6B. Ascidians (Protochordata). Spec Publs Bernice Pauahi Bishop Mus 64(6B): 1–64

Bailey-Brock JH, Hartman O (1987) Class Polychaeta. Reef and Shore fauna of Hawaii. Section 2. Platyhelminthes through Phoronida; Section 3: Sipuncula through Annelida. Spec Publs Bernice Pauahi Bishop Mus 64(2,3): 1–461

Barnard JL (1955) Gammaridean Amphipoda (Crustacea) in the collections of the Bishop Museum. Bull Bernice P Bishop Mus 215: 1–46

Barnard JL (1970) Sublittoral Gammaridea (Amphipoda) of the Hawaiian Islands. Smithson Contrib Zool 34: 1–286

Barnard JL (1971) Keys to the Hawaiian marine Gammaridea, 0–30 meters. Smithson Contr Zool 59: 1–135 pp

Barnard JL, Karaman G (1991) The families and genera of marine gammaridean Amphipoda (except marine gammaroids). Rec Aust Mus (Suppl) 13: 1–866

Bayer FM (1961) The shallow-water Octocorallia of the West Indian region: a manual for marine biologists. Martinus Nijhoff, The Hague

Bergquist PR (1967) Additions to the sponge fauna of the Hawaiian Islands. Micronesica 3: 159–174

Brock VE (1952) A history of the introduction of certain aquatic animals to Hawaii. Bienn Rep Bd Commnrs Agric For Hawaii June: 114–123

Brock VE (1960) The introduction of aquatic animals in Hawaiian waters. Int Revue ges Hydrobiol 45: 463–480

Brock RE (1994) An analysis of benthic communities in the zone of mixing for the Waiau Electrical Generation Facility. Hawaiian Electric Co. Inc., Honolulu (Rep. No. JA619)

Carlton JT (1985) Transoceanic and interoceanic dispersal of coastal marine organisms: the biology of ballast water. Oceanogr mar Biol A Rev 23: 313–371

Carlton JT (1987) Patterns of transoceanic marine biological invasions in the Pacific Ocean. Bull mar Sci 41: 452–465

Carlton JT (1996) Biological invasions and cryptogenic species. Ecology 77: 1653–1655

Carlton JT, Eldredge LG (1999) Introduced and cryptogenic marine and brackish water invertebrates of the Hawaiian Islands (in preparation)

Carlton JT, Geller JB (1993) Ecological roulette: the global transport of non-indigenous marine organisms. Science, NY 261: 78–82

Carlton JT, Reid DM, van Leeuwen H (1995) The role of shipping in the introduction of non-indigenous aquatic organisms to the coastal waters of the United States (other than the Great Lakes) and an analysis of control options. The National Biological Invasions Shipping Study (NABISS) U.S. Coast Guard and the National Sea Grant Program, Washington DC (Rep. No. CG-D-11-95, Gov. Access No. A-294809)

Chapman JH (1988) Invasions of the northeast Pacific by Asian and Atlantic gammaridean amphipod crustaceans, including a new species of *Corophium*. J Crustacean Biol 8: 364–382

Chapman JH, Carlton JT (1991) A test of criteria for introduced species: the global invasion by the isopod *Synidotea laevidorsalis* (Miers, 1881). J Crustacean Biol 11: 386–400

Chapman JH, Dorman JA (1975) Diagnosis, systematics and notes on *Grandidierella japonica* (Amphipoda: Gammaridea) and its introduction to the Pacific coast of the United States. Bull Sth Calif Acad Sci 74: 104–108

Cohen AN, Carlton JT (1995) Non-indigenous aquatic species in a United States estuary: a case study of the biological invasions of the San Francisco Bay and Delta. Report for the US Fish and Wildlife Service and National Sea Grant College Program. National Technical Information Service, Springfield, Virginia (Rep. No. PB96-166525)

Cohen AN, Carlton JT (1998) Accelerating invasion rate in a highly invaded estuary. Science, NY 279: 555–558

Coles SL (1999) Colonization of reef corals in Pearl Harbor, Oahu, Hawaii. Coral Reefs 18: p.28

Coles SL, DeFelice RC, Eldredge LG, Carlton JT (1997) Biodiversity of marine communities in Pearl Harbor, Oahu, Hawaii with observations on introduced exotic species. Tech Rep Bernice Pauahi Bishop Mus 10: 1–76

Cooke WJ (1977) Order Hydroida. Reef and shore fauna of Hawaii. Section 1. Protozoa through Ctenophora. Spec Publs Bernice Pauahi Bishop Mus 64(1): 1–278

Cox D, Gordon G Jr (1970) Estuarine pollution in the State of Hawaii. Vol. 1. Statewide survey. Tech Rep Univ Hawaii Wat Resour Res Cent, Honolulu 31: 61–66

Dall WH, Bartsch P, Rehder HA (1938) A manual of the recent and fossil marine pelecypod molluscs of the Hawaiian Islands. Bull Bernice P Bishop Mus 153: 1–233

Davie PJF (1998) New records of crabs in Hawaii (Crustacea: Decapoda: Brachyura) Occ Pap Bernice P Bishop Mus 56: 63–64

DeFelice RC, Coles SL, Muir D, Eldredge LG (1998) Investigation of the marine communities of Midway harbor and adjacent lagoon, Midway Atoll, Northwestern Hawaiian Islands. Hawaii Biological Survey, Bishop Museum, Honolulu (Contribution No. 1998-014)

Doty MS (1961) *Acanthophora*, a possible invader of the marine flora of Hawaii. Pacif Sci 25: 547–552

Edmondson CH (1933) Reef and shore fauna of Hawaii. 1st edn. Bernice P. Bishop Museum, Honolulu

Edmondson CH (1942) Teredinidae of Hawaii. Occ Pap Bernice P Bishop Mus 17: 97–150

Edmondson CH (1946) Reef and shore fauna of Hawaii. 2nd edn. Bernice P. Bishop Museum, Honolulu

Edmondson CH (1951) Some central Pacific crustaceans. Occ Pap Bernice P Bishop Mus 20: 97–150

Edmondson CH (1962) Xanthidae of Hawaii. Occ Pap Bernice P Bishop Mus 22: 215–309

Edmondson CH, Ingram WM (1939) Fouling organisms in Hawaii. Occ Pap Bernice P Bishop Mus 14: 251–300

Edmondson CH, Wilson IH (1940) The shellfish resources of Hawaii. Proc 6th Pacif Sci Congr 3: 241–243

Evans EC, Buske NL, Grovhoug JG, Guinther EB, Jokiel PL, Kam DTO, Kay EA, Peeling TJ, Smith SV (1974) Pearl Harbor biological survey. Final Report. Naval Undersea Center (NUC), San Diego (Rep No. NUC TN 1128)

Gordon DP, Mawatari SF (1992) Atlas of marine fouling bryozoa of New Zealand ports and harbors. Misc Publs NZ oceanogr Inst 107: 1–52

Grovhoug JG (1976) A preliminary evaluation of environmental indicator systems in Hawaii. Naval Undersea Center (NUC), San Diego (Rep No. NUC TN 1689)

Grovhoug JG (1979) Marine environmental assessment at three sites in Pearl Harbor, Oahu August–October 1978. Naval Ocean Systems Center, San Diego (Rep No. NOSC TR 441)

Grovhoug JG (1992) Evaluation of sediment contamination in Pearl Harbor. Naval command, Control and Ocean Surveillance Center, San Diego (Tech Rep No. 1502)

Grovhoug JG, Rastetter EB (1980) Marine fouling dynamics in Hawaii nearshore ecosystems. A suggested technique for comparison and evaluation. In: International Congress on Marine Corrosion and Fouling. Gráficas Orbe, Madrid, pp 249–266

Hartman O (1966) Polychaetous annelids of the Hawaiian Islands. Occ Pap Bernice P Bishop Mus 23: 163–252

Henry D, McLaughlin P (1975) The barnacles of the *Balanus amphitrite* complex (Cirripedia, Thoracica). Zool Verh, Leiden 141: 1–254

Hilliard RW, Hutchings P, Raaymakers S (1997) Ballast water risk assessment. 12 Queensland ports. State 4 Report – review of candidate risk biota. Ports Corporation of Queensland, Brisbane (EcoPorts Monogr Ser No 13)

Hurlbut CJ (1990) Variations in larval density and settlement in space and time: important determinants of recruitment in sessile marine invertebrates? Ph.D. thesis. University of Hawaii, Honolulu

Ingram W (1937) Fouling organisms in Kaneohe Bay and Pearl Harbor, Oahu. Masters thesis. University of Hawaii, Honolulu

Kay EA (1979) Hawaiian marine shells. Reef and shore fauna of Hawaii. Section 4. Mollusca. Spec Publs Bernice Pauahi Bishop Mus 64(4): 1–652

Kinzie RA III (1968) The ecology of the replacement of *Pseudosquilla ciliata* (Fabricius) by *Gonodactylus falcatus* (Forskal) (Crustacea; Stomatopoda) recently introduced into the Hawaiian Islands. Pacif Sci 22: 465–475

Lambert CC, Lambert G (1998) Non-indigenous ascidians in southern California harbors and marinas. Mar Biol 130: 675–688

Laubenfels MW de (1950) The sponges of Kaneohe Bay, Oahu. Pacif Sci 4: 3–36

Laubenfels MW de (1951) The sponges of the islands of Hawaii. Pacif Sci 5: 256–271

Laubenfels MW de (1957) New sponges and records of Hawaiian sponges. Pacif Sci 11: 236–251

Long ER (1972) Marine fouling studies off Oahu, Hawaii. Veliger 17: 23–36

Maciolek JA (1984) Exotic fishes in Hawaii and other islands of Oceania. In: Courtenay WR, Stauffer JR Jr (eds) Distribution, biology and management of exotic fishes. Johns Hopkins University Press, Baltimore, pp 131–161

McCain JC (1975) Fouling community changes induced by the thermal discharge of a Hawaiian power plant. Envir Pollut 9: 62–83

Monniot C, Monniot F (1997) Records of ascidians from Bahrain, Arabian Gulf, with three new species. J nat Hist 31: 1623–1643

Muir DG (1997) New records of peracarid crustacea in Hawaii (Crustacea: Peracarida) Occ Pap Bernice P Bishop Mus 49: 50–54

Paulay G (1996) New records and synonymies of Hawaiian bivalves (Mollusca). Occ Pap Bernice P Bishop Mus 45: 18–29

Pilsbry HA (1928) Littoral barnacles of the Hawaiian Islands and Japan. Proc Acad nat Sci Philad 79: 305–317

Randall JE (1987) Introductions of marine fishes to the Hawaiian Islands. Bull mar Sci 41: 490–502

Russell DJ (1992) The ecological invasion of Hawaiian reefs by two marine red algae, *Acanthophora spicifera* (Vahl) Boerg and *Hypnea musciformis* (Wulfen) J. Ag., and their association with two native species, *Laurencia nidifica* J. Ag. and *Hypnea cervicomis* J. Ag. ICES mar Sci Symp (Act Symp) 194: 110–125

Ruiz GM, Carlton JT, Grosholz ED, Hines AH (1997) Global invasions of marine and estuarine habitats by non-indigenous species: mechanisms, extent and consequences. Am Zool 37: 621–632

Soule DF, Soule JD (1967) Faunal affinities of some Hawaiian Bryozoa (Ectoprocta). Proc Calif Acad Sci 35: 265–272

Southward AJ, Burton RS, Coles SL, Dando PR, DeFelice R, Hoover J, Newman WA, Parnel E, Yamaguchi T (1998) Invasion of Hawaiian shores by an Atlantic barnacle. Mar Ecol Prog Ser 165: 119–126

Sterling EP, Summers CC (1978) Sites of Oahu. Bishop Museum Press, Honolulu

Straughan D (1969) Serpulidae (Annelida: Polychaeta) from Oahu, Hawaii. Bull Sth Calif Acad Sci 68: 229–240