AQUATIC ECOSYSTEMS OF KEALIA FLOODPLAIN AND MAALAEA BAY, MAUI

EVALUATION FOR PERPETUATION AND PUBLIC USE

BY
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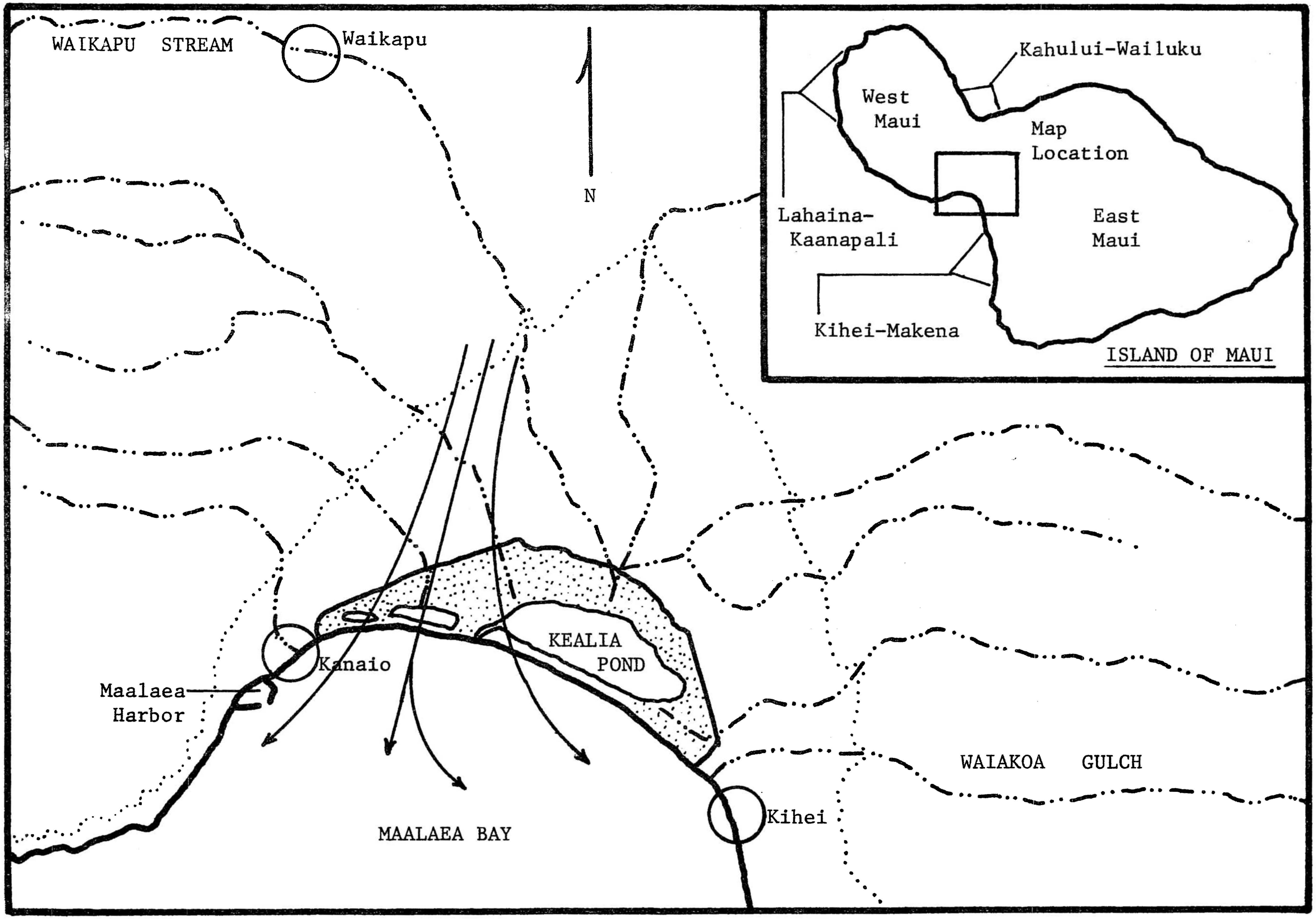
INTRODUCTION

Maui Island comprises 11% of the area of the State of Hawaii but contains only 5% of the State's population according to the 1970 census. Topographic and climatic diversity give Maui natural beauty and tourist appeal. Economic growth based on tourism has accelerated in the past few years to the point where many prime areas are developed and others are under acquisition or planning. One such area is the Kealia Floodplain (Fig. 1) on the shores of Maalaea Bay, the leeward side of the isthmus separating mountainous rises of East and West Maui. It is an open space, central to 3 principal residential areas: Kihei-Makena, Kahului-Wailuku and Lahaina-Kaanapali. The impending considerations for development on this floodplain were suggested in a recent administrative plan (County of Maui, 1970) that includes Kealia:

> "...The Kihei area which abounds in natural amenities; the mild climate, attractive sand beaches, unspoiled natural vistas, a warm and gracious way of life....these fragile assets could be destroyed by the on-rush of insensitive and unrestricted development that is sure to come. It would be tragic if this happens. ..."

Shortly after that plan was published, use interests converged on Kealia. In spring 1970, the active water-related interests included: harbor development (U. S. Army, Corps of Engineers), commercial aquaculture (Fishfarms Hawaii), shrimp-laboratory (Maui Office of Economic Opportunity) and water bird refuge (U. S. Bureau of Sport Fisheries and Wildlife). Obvious conflicts among these interests, and the irreversible modification suggested by harbor dredging, led to the initiation (April 1970) of a personal study of the aquatic ecosystems which is the basis for this report.

Fig. 1. Sketch map of the Kealia Floodplain (stippled area) and Maalaea Bay, Maui, with location inset. Major drainage channels are indicated by interrupted lines; the two named (Waiakoa Gulch, Waikapu Stream) are described in text. Dotted line is the 100 foot elevation contour. Circles denote small residential communities; major residential areas of island are shown on inset map. Long arrows indicate characteristic daytime surface wind flow (from U. S. Weather Bureau data).


WAIKAPU STREAM
Waikapu
N
Kahului-Wailuku
West Maui
Map Location
Lahaina-Kaanapali
East Maui
Kihei-Makena
ISLAND OF MAUI
KEALIA POND
Kanaio
Maalaea Harbor
MAALAEA BAY
Kihei
WAIAKOA GULCH

Since then, aquaculture became established, harbor plans were left dormant, the shrimp laboratory was withdrawn (site unsuitability), the refuge proposal continued under official review, and Maui Electric Co. applied for a permit to construct a 200-megawatt generating plant (permit granted for diesel and gas-turbine generation only).

Preliminary study showed that the Kealia-Maalaea area had considerable natural value and public use[1] potential. This immediately contrasted with active development interests, all but one being special use. Portions of an ecosystem (Kealia Floodplain) were being contested without planners, developers, or permit-granting bodies having significant information of the area's ecology or how proposed development would influence its ecosystems.

The Kealia-Maalaea area contains two interrelated primary aquatic ecosystems, Kealia Pond and the adjacent inshore waters of Maalaea Bay. A third system, hinterland drainages, also must be considered because its runoff waters strongly influence the two primary systems. This report attempts a comprehensive description to indicate possible developmental disturbances and to suggest ways to protect and utilize the ecosystems for greatest public benefit while maintaining high natural quality.

This study was supported largely by the U. S. Bureau of Sport Fisheries and Wildlife, Division of Fishery Services. Observations and opinions expressed herein are solely those of the author unless qualified otherwise. Many persons offered helpful manuscript critique; special thanks are due to Drs. E. Alison Kay and Sidney J. Townsley of the University of Hawaii, and to Dr. Roy T. Tsuda of the University of Guam, for their evaluation of Maalaea Bay biota.

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[1]Public use is here taken to mean all non-special or non-private uses regardless of their possible ultimate public benefit. Public use thus includes esthetics, recreation, sport, and science. The latter has a two-fold connotation, public education and the research on which it is based.

LAND DRAINAGE

Kealia Floodplain (Fig. 1) is a depositional feature of runoff waters from highlands of both East and West Maui, entering Maalaea Bay as a single discharge from Kealia Pond at Palalau. Runoff containing sufficient mineral detritus to cause significant deposition on the floodplain and siltation[2] in Maalaea Bay results from occasional winter frontal-cyclonic storms. It arrives via a series of gulches that either coalesce in the canefields to the north, or enter Kealia Pond independently. Other gulches influencing Maalaea Bay, particularly through silt discharge, occur in the Kihei area and are independent of the Kealia Floodplain. Waiakoa is one of these and this gulch, together with Waikapu Stream of the Kealia system, serve to demonstrate runoff features.

Waiakoa Gulch (Fig. 1) drains a portion of west Haleakala through the Kula area and discharges into Maalaea Bay at the Kihei highway intersection. The gulch is normally dry, therefore without indigent biota. Serious flood discharge is infrequent, occurring only in two of the eight years reported by Ewart (1971)[3]. To these observations, can be added the Waiakoa flooding of 1971 which swept two motor vehicles into Maalaea Bay. Accompanying silt enters the Bay and persists over a large area around the discharge point. Channel modification has been minor and some of this silt is a natural circumstance. But silt load has been enhanced by bank and field erosion resulting from cultural influence (grazing, field crops, land development).

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[2]Used here in a non-technical sense to include fine sand, silt, clay and organic detritus.

[3]Personal judgment based on peak flows >300 cfs for 1963 and 1967. Trace maximum flow occurred in 1965, and no flow is indicated for 1964 and 1966.

For example, severe silt runoff from Kula Highlands (a residential subdivision at 3,100 ft. elevation implemented in 1970) occurred during winter 1971 storms. Such turbid discharges appear to be responsible for the generally poor quality of inshore water in eastern Maalaea Bay and probably influence the western part of the Bay described subsequently.

Waikapu Stream drains the southeastern part of West Maui via a deeply-eroded valley. The channel descends a mature alluvial fan at the valley mouth, traverses the canefields of south Central Maui and enters Kealia Pond at a central point (Fig. 1). Waikapu channel as well as lesser gulches have been straightened in the canefield zone where they receive drainage from field ditches. Waikapu is a perennial stream at higher elevations. In a natural state, it was a continuous surface flowage throughout its course and is assumed to have had a complement of native faunal species. At least in the historic past, Waikapu represented a permanent and comparatively stable stream ecosystem.

Total diversion of all but peak flows at 1,100 ft. elevation was accomplished many years ago for the purpose of cane irrigation. Native stream species, mostly dependent upon frequent migrations to and from the sea, have all but disappeared. A brief survey of Waikapu above the diversion intake in 1967 evidenced only opae (shrimp, *Atya bisulcata*) and insects among the macrofauna present. The stream channel below diversion point now resembles the normally-dry gulches.

Waikapu is the principal influent to Kealia Pond, and therefore to the western part of Maalaea Bay. It floods more frequently than Waiakoa, although the season and cause are the same. Ignoring duration, peak flows exceeding 500 cfs were reported in 5 out of 8 years by Ewart (1971). Prior to agricultural modification, the Waikapu system probably discharged silt at a relatively low rate. Accelerated silt discharge in the recent past is suggested by various observations. One is that the vertical profile of sediments in Kealia basin shows a few feet of high-mineral deposit overlying an organically-rich layer[4], indicative of a deeper pre-cultural basin that received silt at a low rate. Another is that the bottom topography of Maalaea Bay indicates vigorous reef development in the past that now appears decimated (except in the Palalau sub-area described subsequently). Lastly, removal of permanent vegetative cover and the straightening of drainage channels in the canefield zone might be expected to enhance erosion, or at least preclude sedimentation in an otherwise "depositional" area. Regardless of source, silt discharge from this hinterland is an extremely important environmental consideration.

KEALIA POND AND FLOODPLAIN

General Description and Biota

Kealia Floodplain is considered here to be the largely undeveloped region between residential areas of Kanaio on the west and Kihei on the southeast (Fig. 1). It is bordered in part by beach, highways, and canefield as shown in Figs. 2 and 3. The floodplain is actually larger, but these boundaries facilitate description and discussion of the undeveloped ecosystem. Shallow, ponded water occupies 400-500 acres during winter and spring as a result of the runoff described previously. Most of this is Kealia Pond, but lesser ponds appear to the west, between the coast highway and the Bay. Land surrounding the ponds, vegetated mostly by shrubby salt-tolerant Batis and kiawe trees, covers at least an equal acreage.

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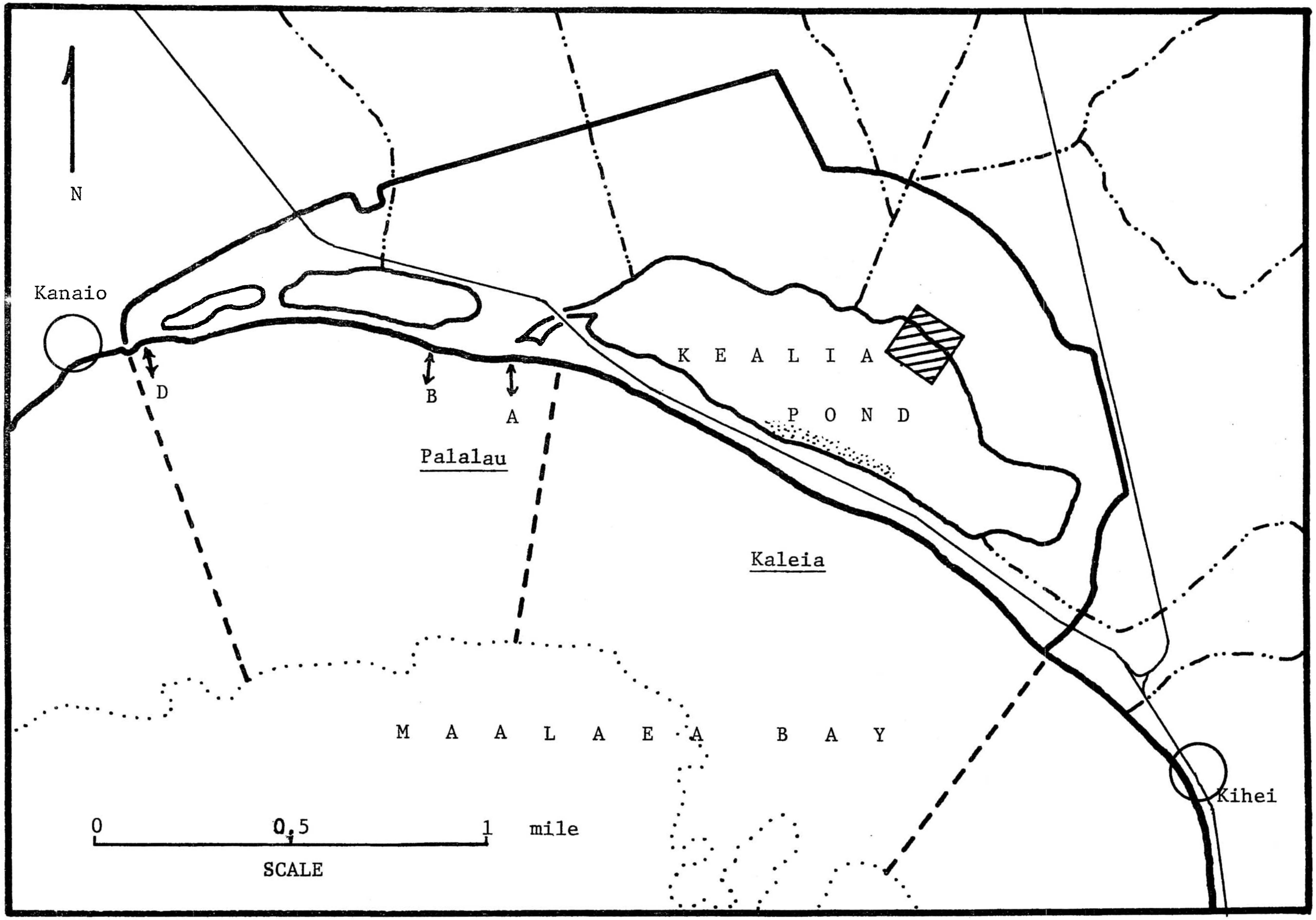
[4]Personal communication, Carter Pyle, Fishfarms Hawaii.

Usually, the open standing water disappears in summer in response to seasonal climatic change, leaving the dry pond bottoms exposed to wind erosion. The floodplain receives little precipitation, less than 15 inches per year. Strong northerly winds, described further in the Maalaea Bay section, are prevalent.

Inundated Kealia Pond (Fig. 3) becomes habitat for various waterfowl (ducks, geese, coots), wading birds (stilts, turnstones, sanderlings, night herons, etc.), and aquatic biota upon which they feed. The latter includes many small invertebrates, a few native macrofaunal species such as milkfish (*Chanos chanos*), mullet (*Mugil* sp.), aholehole (*Kuhlia sandvicensis*), river opae (*Macrobrachium grandimanus*), brown wi (*Theodoxus* [*Neritina*] *vespertina*) and snails (*Melania mauiensis*), and also exotic animals (tilapia, crayfish, various poeciliid fishes such as *Gambusia*) that constitute the bulk of the biomass. Permanent freshwater occurs in ponds and depressions within the kiawe thicket to the north. These are presumed to act as havens for aquatic fauna during dry periods, as well as sources of animals colonizing Kealia Pond during the wet season.

Pond water disappears in summer mainly through evaporation as evidenced by a light salt crust residue (gypsum marginally and halite centrally). Kealia and accessory pond basins are very flat, seemingly poorly permeable, and only slightly above sea level. Runoff water is low in dissolved ions; salts could enter the system as sea spray during Kona (southerly) wind conditions or possibly by vertical transfer from the near-surface water table. Salt accumulation in the system may be retarded by deflation, by percolation, or by both. In the final stages of drying, a massive dieoff of aquatic fauna occurs (Fig. 4). The reduction of Kealia Pond surface area from about 50% of the basin to total dryness in July 1971 required less than 3 weeks.

Fig. 2. Detail map of Kealia Floodplain and Maalaea Bay, Maui. Heavy line encloses floodplain and pond basins, undeveloped except for aquaculture operation (shaded square). Interrupted lines are major land drainage channels; fine lines are highways. Stippled area on seaward side of Kealia Pond indicates suggested location of dredged subbasin for fishery or fish removal facility (see Discussion). Heavy dashed lines in inshore marine area are assumed limits of Palalau and Kaleia subareas that are bounded on the seaward side by the 10-fathom depth contour (dotted line). Small arrows denote transects A, B and D described in text.


N
Kanaio
D
B
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Palalau
K E A L I A
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Kaleia
M A A L A E A B A Y
Kihei
0
0.5
1
mile
SCALE

Problems: Silt, Dust and Odor

Waterborne silt in Maalaea Bay is esthetically objectionable and a hazard to the marine ecosystem. Blowing dust and odor from decomposing aquatic fauna have been deemed a public nuisance. These are consequences of the Pond's unusual dynamics but are not without redeeming value.

As silt-laden water enters Kealia Pond during winter freshet conditions, its velocity is greatly reduced and much of the particulate matter settles to the bottom. Water level rises, causing momentary flooding, until the beach bar of the outlet channel (at transect A in Fig. 2) is breached and excess water is decanted. Water discharged into the ocean contains some particulate matter (especially the clay fraction). Under present conditions, this turbidity is not severe enough to destroy or decimate the Maalaea coral reef community (see later) living at and to the west of the discharge point.

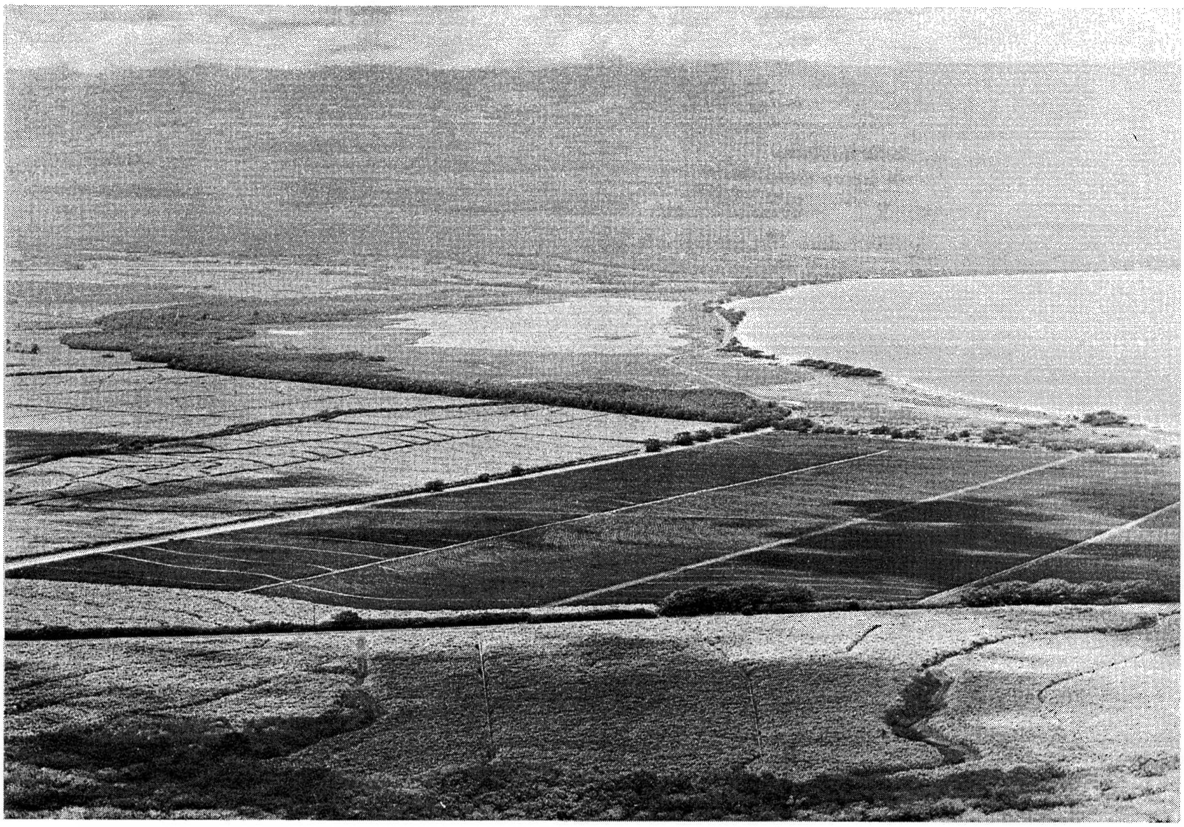
Dry sediments are excavated in summer and fall by prevailing trade winds (Fig. 1), probably aided by vertical (downward) eddys induced by the kiawe thicket. Dust blows seaward, occasionally obscuring the coastal highway enroute to distribution over a vast area. Most dust is carried beyond inshore Maalaea waters, eliminating the harm of a concentrated deposition. Wind varies in speed and direction in a diel cycle, usually blowing strongest from late morning through afternoon. The generalized pattern shown in Fig. 1 may vary considerably; dust has been observed blowing directly eastward across the pond. Airborne dust frequently reaches the Kihei-Makena coast to the southeast. Some residents of these areas consider Kealia Pond the source of their dust problem. However, observations during dry seasons convinced this writer that much (probably most) of the problem dust derives from bare canefields of central Maui,

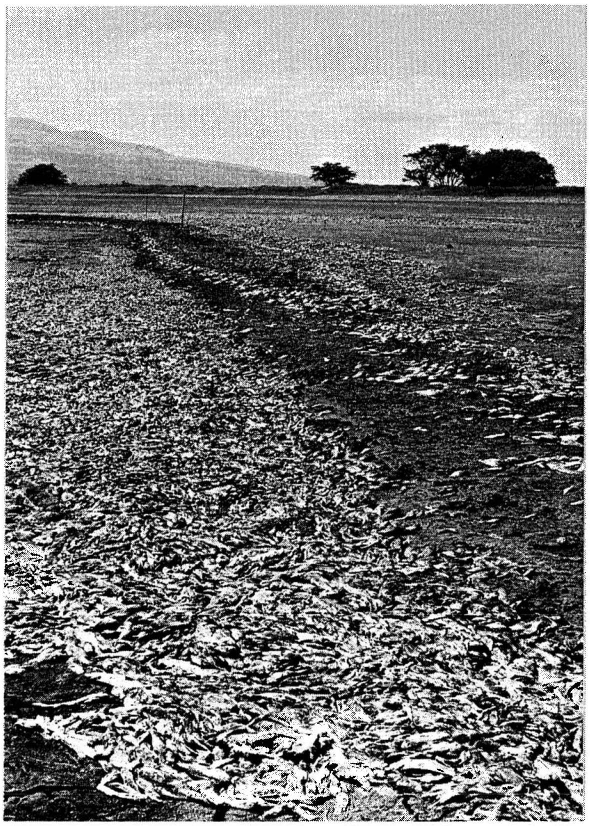
Fig. 3. View of the Kealia-Maalaea area looking southeastward from Kealaloa Ridge, West Maui. Light area in picture center is Kealia Pond, which has past high water stage and is beginning to dry out (photo taken June 1971). Light colored vegetation surrounding pond is shrubby Batis; darker vegetation extending to perimeter of undeveloped floodplain is kiawe tree thicket. Smaller gulches meander through canefield in foreground (light fields are growing cane, dark fields are furrowed and recently replanted. Slopes of Haleakala (E. Maui) rise into clouds in background.

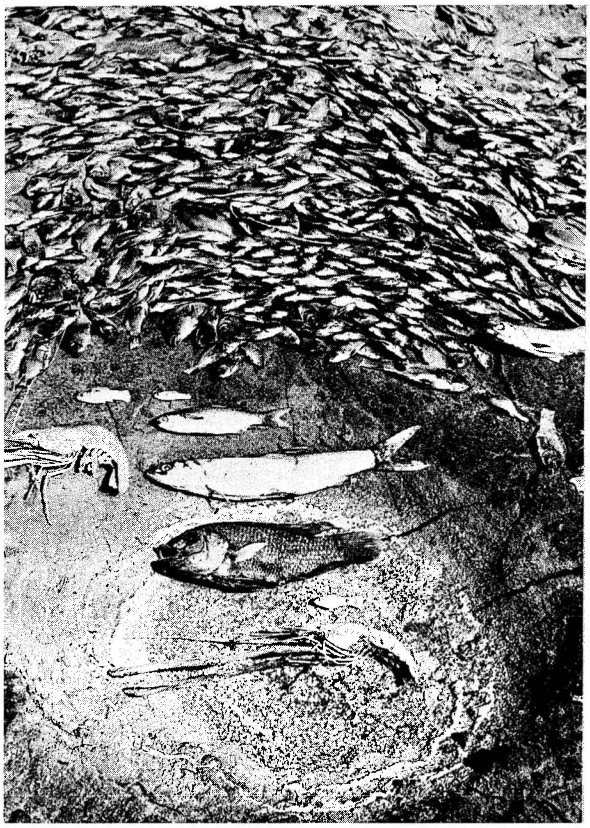
Fig. 4. Summer desiccation mortality of Kealia Pond fauna observed July 1971.

Fig. 4a. A portion of the broad band of carcasses deposited across the central and seaward part of the basin. Dead biomass consists almost entirely ($>$ 90%) of the introduced cichlid, Tilapia mossambica.

Fig. 4b. Species in the kill include tilapia (dark specimen), milkfish or awa (Chanos chanos, large light specimen), mullet (Mugil cephalus, above awa), and small topminnows (unidentified poeciliids). Crustacean is Malaysian prawn (Macrobrachium rosenbergii) escaped from aquaculture ponds during January flooding. Depression is tilapia redd.







especially those being harvested or tilled (cf., County of Maui, 1970, p. 28). Regardless of immediate source, the dust problem ultimately relates to agriculture in the central Maui isthmus.

Technically, Kealia Pond is a settling and deflation basin maintained by wind erosion of deposited silt. These two natural processes, acting in succession, protect the inshore marine ecosystem from over-siltation. Permanent inundation would preclude deflation, accumulating silt would fill the basin, and vegetation (*Batis*) would likely invade all of it. In response to the rising floodplain, influent drainages would tend to channelize directly to the ocean, and a valuable marine ecosystem would be lost in perpetually-turbid water. Blowing dust, which some want to eliminate, actually is a benefit to this important natural marine resource. There is no assurance that even natural processes will allow the pond basin to persist indefinitely. The situation should be kept under surveillance and technical assistance called upon if the balance changes to threaten further siltation of Maalaea Bay.

Odor emanating from the faunal dieoff during final stages of pond desiccation is obvious, but short-term. This mortality, shown in Fig. 4, consisted mostly of tilapia accompanied by a small percentage of milkfish, mullet, poeciliids and prawns. At that time (July 19), the carcasses were virtually dry and not much odor was evident; two weeks earlier, these animals were alive. Permanent flooding would not necessarily eliminate odor because Kealia Pond is disposed to organic richness. Kanaha, a perennial, organically-rich pond on the north of Maui's isthmus has a protracted odor problem that is the concern of the State administration.

Existing and Potential Aquatic Uses

1. Bird refuge.

Maui Island has only two significant waterfowl-shorebird sanctuaries, Kanaha and Kealia Ponds. They are used by many migratory species, but more important is the habitat they provide for three endemic birds: Hawaiian stilt (Aeo), Hawaiian coot (Alae Keokeo), and black-crowned night heron (Aukuu). Kealia Pond accommodates many birds during winter and spring when it is inundated. Even during the dry season, Aukuu roost in the floodplain's kiawe trees. Kanaha Pond is perennial and therefore provides complete habitat requirements for the endemic water birds. However, despite the large sign reading "Permanent Home of the Rare Hawaiian Stilt or Aeo", Kanaha Pond is not a dedicated sanctuary and lives under threats of commercial-industrial development and ultimate complete eutrophication.

Understandably, concerned public agencies and private conservation groups look to Kealia Pond as a secondary sanctuary site. In order to make it into a permanent bird refuge (having all habitat requirements of endemic species) with a high public-use factor, careful planning and a certain amount of development is necessary. Plans to do so must surely take into account the existing ecological role of the pond as described previously. Refuge design must allow siltation to occur and the silt to be removed in some manner.

2. Aquaculture.

Aquaculture was established (fall 1970) on a small area of central Kealia Pond (Fig. 2). The operation does not utilize surface water but draws from slightly brackish shallow wells located in the kiawe zone on the east side of the floodplain. Catfish (Ictalurus punctatus) and Malaysian prawn (Macrobrachium rosenbergii) are current culture animals.

It is presently in a feasibility stage and has the possibility of expanding in area to cover a few hundred acres. This enterprise has been viewed favorably as a new facet for Maui's economy and agricultural diversity. Also favorable for conservation purposes is the management's consideration of maintaining a small waterbird refuge. As a commercial (or production) operation, it has the disadvantage of a low public-use factor. If extensive aquaculture is projected for Kealia Pond, at least two environmental factors deserve serious consideration. The first is the silt-removing capability of the present basin. Original development plans included channelization of runoff water to direct ocean discharge. <u>For reasons previously and subsequently described, this channelization is ecologically unacceptable</u>.

The second environmental factor concerns nutrient enrichment of inshore marine waters. Efficient, profitable culture requires intensification--raising a large weight of product per unit water volume. Necessary fertilization and supplementary feeding enrich the culture water, as do the body wastes of the organisms grown. Voiding large amounts of such water into Maalaea Bay, whether by surface runoff or seepage, can seriously reduce water clarity and upset the ecological balance. Low concentrations of dissolved nutrients are characteristic of these sub-tropical waters. Adapted to this is the benthic community whose primary production, accomplished by diverse seaweeds and algal symbionts within tissues of corals and other invertebrates, requires clear water for adequate illumination. Excessive nutrient input (particularly nitrogenous) has two detrimental effects: it promotes phytoplankton that absorbs radiant energy at the expense of benthic growth; it encourages one or a few macrophytes to dominate the benthos, displacing many species of algae and animals. Both effects are now evident in Kaneohe Bay, Oahu (Banner and Bailey, 1970). Severity of this potential problem at Kealia depends upon interrelationships among culture volume and intensity, nutrient concentration, water release to the sea, and nearshore circulation patterns.

3. Recreational fishery.

Kealia Pond does not now represent a public fishery resource although fishes are seasonally abundant. This is because interim refuge status prohibits public entry, the physical nature of the pond is not conducive to fishing, and the principal faunal biomass is tilapia (cf., Fig. 4), a species that is not particularly desirable for either sport or food. A fishing facility at Kealia should be given serious consideration in that it represents high public use, particularly with expanding recreational needs, and is amenable to conservation and open space concepts. As stressed in the foregoing, however, any development for this purpose should not seriously reduce the silt retaining capacity of the pond, nor in other ways pose a threat to the Maalaea marine ecosystem. Such a fishing area necessarily would be limited in size to avoid conflict with other public uses, including bird sanctuary.

Recreational fishing is here taken to mean angling, preferably for sport species that are also palatable. It is the author's belief that a public fishery should be implemented with youth in mind because they are in greatest need of such recreation and the least privileged with respect to access and equipment necessary for successful marine (shoreline and offshore) fishing. Several approaches to recreational fishing on the Kealia Floodplain are possible. Two of them are described in the terminal part of this report.

MAALAEA INSHORE WATERS

Maalaea Bay is the only large leeward Hawaiian bight that is protected from normal open-ocean swells by surrounding islands and has a bottom profile sloping gently into a relatively shallow offshore basin. Consequently, its inshore waters are unlike those found elsewhere in Hawaii in several respects. Decades ago, Edmondson (1933) noted that Maalaea was one of the best areas for collecting marine fauna on Maui. The primary purpose of this report is to characterize that uniqueness and relate it to public use. Descriptions below emphasize nearshore Palalau sub-area (Fig. 2) and further include all waters between Kanaio on the west and Kihei on the east, extending seaward to a depth of 10 fathoms (60 ft.)[5]. These assumed boundaries do not delimit the general ecosystem which extends as a gradually-changing continuum to all adjacent marine waters. Although not considered further herein, it should be noted that factors operating beyond these boundaries could influence the Maalaea inshore marine ecosystem.

Physical Features and Subareas

Heretofore, Maalaea Bay has drawn little attention from scientists and descriptive information is meager. Shoreline topography is unimpressive except for the sweeping length of sandy beach. Moberly (1963) devotes a few sentences to the Bay in his lengthy report on Hawaiian coastal geology, indicating that the barrier beach coast (segment considered here) is distinct from that on either side. He further notes that this shoreline is a gentle arc of beach with beachrock exposures throughout.

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[5] An arbitrary maximum limit for shore-access activities.

Winds are often strong, as noted earlier, because the area lies in the throat of a venturi funnel formed by East and West Maui Mountains with respect to prevailing trades. A generalized wind pattern is shown in Fig. 1, but departures from this are common. Under normal tradewind conditions, a daily pattern variation can be anticipated. Mornings are usually calm with the nearshore water surface often placid. Winds pick up about mid-morning, reaching maximum velocity (which exceeds windward tradewind velocity) by noon. Direction is usually offshore but may become longshore to the east. The wind produces a fine, sharp chop on inshore waters that is not large enough to interfere with snorkeling. Strong winds abate in late afternoon or evening. Ocean waves are often small (<1 m) or absent (cf., Fig. 5a and b). Large waves may appear with southerly winds or result from strong storm systems to the south.

Water current patterns have not been described for inshore Maalaea Bay. Obvious currents (tidal or wind-induced) have not been detected while diving during the course of this study. Yet such currents, albeit gentle, must exist and are suggested only by indirect evidence (winds, biota distribution, turbidity). Initially, Maalaea Bay was divided into two subareas, Kaleia and Palalau, as shown in Fig. 2. Cursory examinations of both subareas indicated a difference: Kaleia water was generally (often significantly) turbid while Palalau was predictably clear; Palalau had far greater species and habitat diversities than Kaleia. This difference is presumed to result from current patterns.

Surface currents are assumed to reflect wind patterns (Fig. 1). West Palalau, in the center of windstress, would have offshore surface transport possibly replaced by bottom water in the manner of a vertical gyre. Such circulation could account for the great species diversity (described later) and the presence of deep water forms in very shallow water. Wind-driven surface currents in Kaleia, however, might establish a counter-clockwise horizontal gyre which would tend to keep poorly-settleable particles from Waiakoa and adjacent gulch discharges in prolonged nearshore circulation. Such a current system could account for the observable turbidity in the eastern part of Maalaea Bay. Even if these presumed current patterns do not exist, it is apparent that the inshore waters of Maalaea Bay do not exchange freely or rapidly with offshore waters. Therefore, the inshore ecosystem is relatively vulnerable to external land-derived influences.

Palalau and Its Biota

1. General description.

Palalau subarea (Fig. 2) extends longshore for nearly one mile from the eastside of Kealia Pond outlet westward to the small residential area at Kanaio. The sandy shoreline is broken in several places by beachrock outcroppings (Fig. 5). This rock forms an extensive intertidal bench on the east end of Palalau that retains a large pool at low tide. A smaller, deeper tidepool system is formed similarly at the west end of the subarea. The ottom slopes gently downward to the 10-fathom contour nearly a mile offshore. Nearshore (to 3 fathoms), rock predominates with interspersed sandy channels and patches. This rock often has a low, flat-topped profile, especially in the eastern part of the subarea. Further offshore, sand becomes progressively more abundant. These waters are seasonally clear (summer, fall, early winter); subjective visibility can be estimated from the photographs in Fig. 5. Average transparency is not exceptional, but allows a surface snorkeler to view the bottom over the entire area. Turbidity occurs when silty waters discharge from Kealia Pond and when

Fig. 5. Views of the marine ecosystem at Palalau emphasizing shore zonation and stony corals. Photographs were taken between September 1970 and March 1971; submarine views in water no deeper than 3 fathoms.

a,b). Shoreline views with Kealaloa Ridge (W. Maui) in background. a). Coralline rocks dot the beach and merge with clear shoreline water by transect area B (cf., Fig. 2). b). Low tide exposes Sargassum-covered beachrock bench retaining large tidepool near Kealia Pond outlet (transect A, Fig. 2).

c,d). Two of the subtidal zones. c). Seaward face of beachrock bench with burrowing urchins (Echinometra mathei), several species of algae and a common shallow-water coral (Pocillopora cespitosa). d). Clumps of green alga (Ulva reticulata) are scattered about the bottom in water less than a fathom deep near coral colony (Porites lobata) adorned with pink nudibranch (Hexabranchus sp.) eggs.

e,f). Colonies of an uncommon coral, Pocillopora modumanensis. Characteristic of deeper waters, it was found at Palalau at depths less than a fathom. Colony on left provides shelter for black and white damselfish, Dascyllus albisella. Small projections rising from bottom behind colony on right are sabellid worm tubes.

g,h). Some species and growth forms of the coral genus Montipora. g). Furrow structure reminiscent of a petroglyph in colony of M. patula. Such grooves are maintained by alpheid shrimps in several species of encrusting corals (cf., 5d, above). h). Projecting semi-circular brownish plate is M. verrucosa adjacent to crustose bluish M. flabellata.





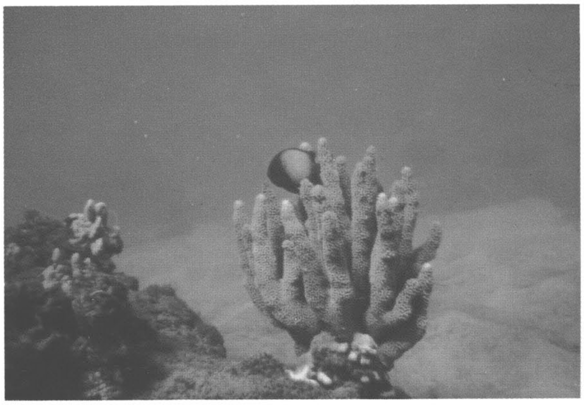
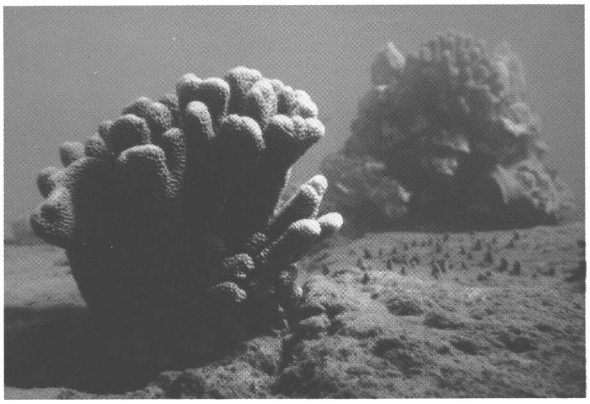
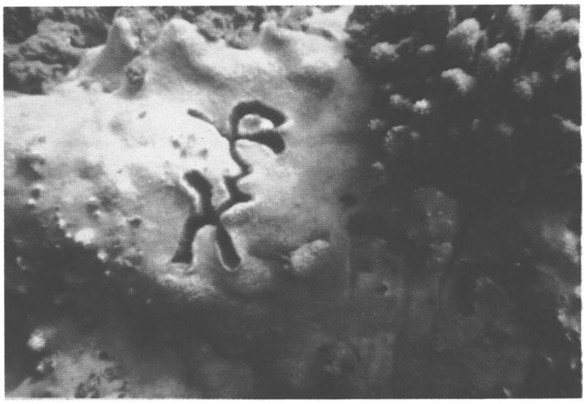




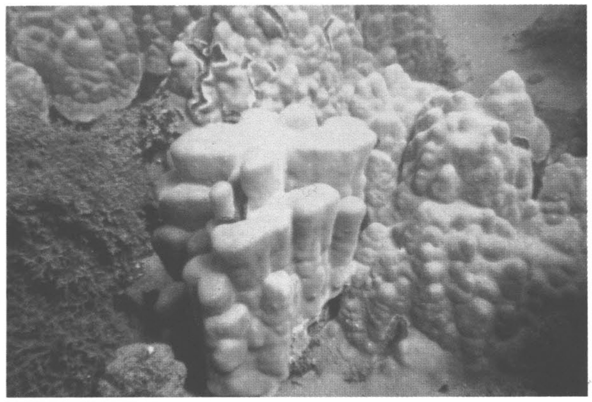
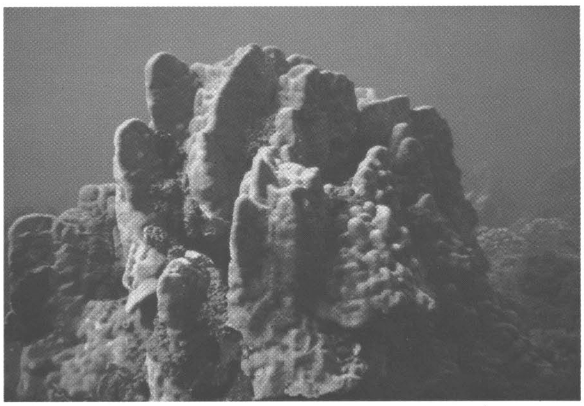
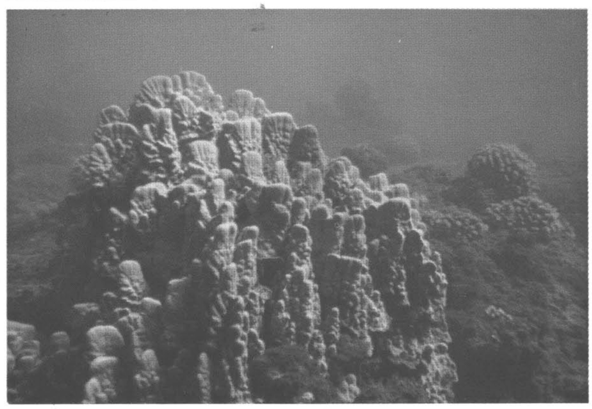
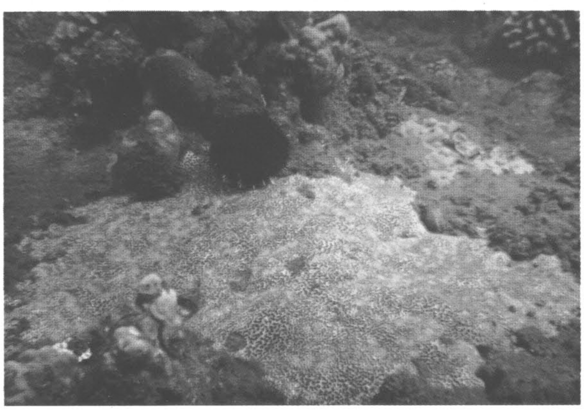
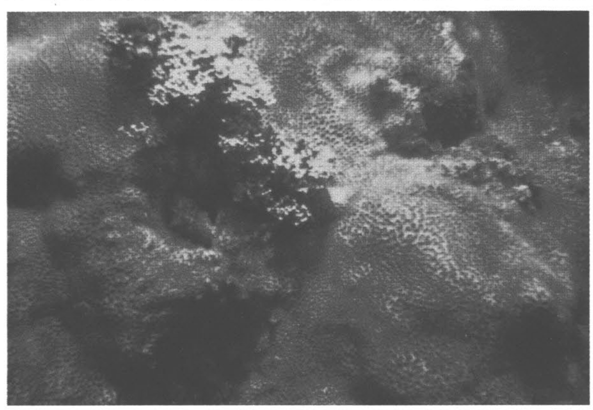
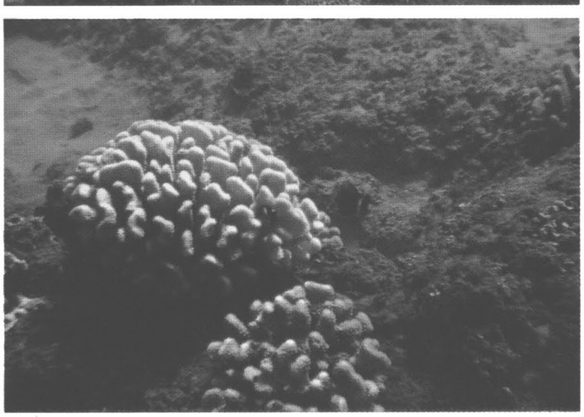
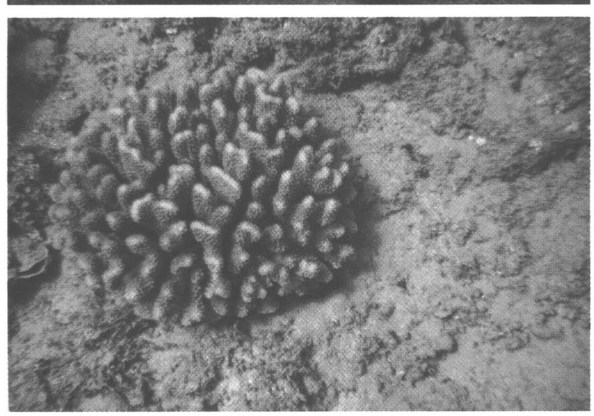

Fig. 5. (continued--Palalau stony corals)

i,j). *Porites*, one of the most ubiquitous Hawaiian corals, often forms expansive colonies. i). Large head of common *P. lobata*. j). Less common *P. evermanni*, characterized by flat-topped lobes, grows adjacent to bright yellow *P. lobata*.

k,l). Massive heads of *Pavona explanulata* viewed from different angles. The fan-topped apical lobes distinguish this species.

m,n). Leptastrean corals (*Leptastrea purpurea*?) having large, easily seen calices (polyp pits) and a flat, sprawling colony structure. m). Whitish colony with purple urchin (*Tripneustes*) at top center. n). Brownish colony with coralline alga (*Porolithon*) growing from center.

o,p). Three of the many color phases of the common coral *Pocillopora meandrina*. Globose colony structure and profuse branching provides abundant interstitial shelter for small fishes, crabs, mollusks, and other fauna.

large southerly swells disturb settled silt. Clearing requires a few days to several weeks, depending upon the cause and severity of turbidity.

The most important feature of this ecosystem is the diversity of biota and its occurrence in differentiable communities, both in seaward profile and laterally along shore. This may not be immediately apparent to the casual viewer but a trained scientific eye is not required to appreciate the remarkable assemblage of organisms as observation is continued. Major taxa of seaweeds and marine animals are well represented.

It is not yet possible to describe this biocoenosis in detail but observations indicate considerable species diversity at least among the algae, corals, mollusks, decapod crustaceans and echinoderms. The first three groups are described further in separate sections below. Fishes were not surveyed specifically although a variety was evident. Most abundant were small demersal species and juveniles of several families, such as goatfishes, surgeonfishes and butterflyfishes. Maalaea Bay may well be a valuable nursery area. Zonation of benthic communities seaward from the tidepools, across the beachrock benches (Fig. 5), through lateral sand channels to deeper rock outcroppings possibly are the best example of this ecological phenomenon in Hawaii. This intertidal-subtidal zonation is more developed on the eastern end of Palalau (Fig. 2, Transects A and B).

Larger sedentary benthic organisms not only are the most obvious among Palalau biota, but they form the basic members of each community because of their large biomasses and their inability to migrate. Some of these species, stony corals for example, require many years to attain mature growth form. Being sedentary also means that such biota must withstand environmental stresses, natural and induced, if their communities are to persist. Thusfar, they have persisted.

The two most prominent groups of sedentary biota, seaweeds and stony corals, are described below. The region in which they were examined extends from the shoreline to a depth no greater than 5 fathoms--the prime snorkeling area. Biota of the deeper zone, 5-10 fathoms, was not examined. However, these deeper waters are known to contain uncommon and unusual species (e.g., white spindle shell, chick-pea cowry).

2. Algal macrophytes.

Seaweeds are the most conspicuous and varied forms of life in the waters nearest shore. They were surveyed by Dr. Roy T. Tsuda on 10 July 1971 along 3 transects as shown in Fig. 2. Transects began at the water's edge and extended seaward to a depth of 2 fathoms (horizontal distance ca. 300 feet). A total of 59 species of macrophytes, exclusive of encrusting forms, was collected. Their classification within major taxons is summarize below.

	Number of species, each transect			Number, all transects	
Division	A	B	D	Genera	Species
Cyanophyta (blue-greens)	2	1	0	2	2
Chlorophyta (greens)	9	9	7	10	16
Phaeophyta (browns)	11	8	4	10	14
Rhodophyta (reds)	12	17	12	25	27
Total	34	35	23	47	59

A check list of genera is provided in the appendix. The 59 species represent 1/6 of known Hawaiian species. Dr. Tsuda remarked that this was one of the most diverse Hawaiian algal communities he had seen, adding that further collections at different seasons could well double the number of identifiable species. If true, Palalau could claim to possess a third of all Hawaiian seaweeds, a remarkable situation. This floral diversity should be relfected in a correspondingly large number of small animal species.

Species diversity also indicates a habitat diversity that can be estimated by zonation and transect dissimilarity. The number of identifiable zones along each transect were: Transect A, 6 zones; Transect B, 6 zones; Transect D, 4 zones. Transects were dissimilar to the extent that the same species encountered on: A and B = 42%; B and D = 28%; A and D = 22%. Only 15% of the species were common to all three transects.

3. Stony corals.

The most prominent faunal group of Palalau's inshore waters are the stony corals, occurring seaward from the immediate subtidal zone of the beachrock bench. They are striking because of their large, impressive growth forms and the attractive colors caused by their algal symbionts. Some of the Palalau corals are shown in Fig. 5. Abundant rock outcroppings provide considerable area for colony attachment. Greatest species diversity is encountered in water one to three fathoms deep. Because corals develop slowly and require considerable light for healthy growth, it is assumed that favorable environmental conditions have existed in the Palalau subarea for many decades.

Corals were examined in the vicinity of Transects A, B and D (Fig. 2) by Dr. Sidney J. Townsley on 21 August 1971. Specimens were not removed from the ecosystem, a procedure necessary for the positive identification (laboratory) of certain species. Dr. Townsley indicated that at least 20 species were present, 17 of which were easily recognized in the field.

These 17 species occurred in 6 genera, as follows (each genus represents a separate madreporarian family): Montipora, 4 species; Pavona, 2 species; Fungia, 2 species; Leptastrea, 2 species; Pocillopora, 4 species; Porites, 3 species.

Differences in species dominance and abundance in different parts of the Palalau area was striking in a way similar to that described for the algae. Near Transect A, coral heads were generally scattered with at least 13 species represented. This community was dominated by Pocillopora and included several heads of P. modumanensis--an uncommon endemic usually associated with deep water habitat. The absence of crowding allows many species to develop without space competition, thereby attaining characteristic colony features. Diversity plus lack of crowding suggest that this community exists under stress and might easily succumb if care is not taken to avoid increased stress.

An entirely different community exists at the western end of Palalau. There, corals grow in great profusion, strongly dominated by Porites and Montipora. One of the less common corals found there is Fungia patella [Cycloseris vaughni]. Inasmuch as this community covers a very restricted area, it also appears to thrive in a delicate balance with environmental factors. The great habitat and species diversities within the small Palalau area deserve serious conservation considerations.

4. Mollusks.

Mollusca is one of the best represented of all inshore faunal phyla, although less conspicuous than most others. A preliminary survey of this group was made by Dr. E. Alison Kay in the Palalau subarea based on shells present in beachdrift (one 75 cc sample taken June 1970) and shallow water sediment samples (four, totalling 90 cc taken 21 August 1971). Species were identified and the numbers of individuals tallied by careful microscopic examination of the substrate material. Not all species present are evaluated by this technique. It includes only shells shorter than 1 cm, primarily the inherently minute species and also smaller shells of some larger species. Advantages of this technique are that it is usable in any area having fine unconsolidated sediments or drift, it samples most of the species present with minimal effort, and therefore allows quantitative and qualitative inter-area comparisons.

Analyses showed that the samples contained 165 species in 87 genera. These represented 39 families of gastropods and 10 families of bivalves, as listed in Appendix Table 2. Sediment samples contained 1,435 shells for an average abundance of 16 shells per cubic centimeter. Below is a summarial tabulation of species occurrence by location in the four samples.

Reference Locality	Number of Species	Percentage of Total
East Palalau Only	46	42
West Palalau Only	11	10
Both Locations	52	48

Fifty-two species, comprising less than half of the total, were common to both ends of the Palalau subarea. Greater diversity was found in the eastern side (at transects A and B, Fig. 2). A corresponding diversity of habitats is suggested by the lack of dominance of any single species; most abundant was *Rissoina miltozona*, less than 15% by number.

The samples contained conspicuous deepwater species in the genera *Scaliola*, *Diala* and *Obtortio*. Particularly noteworthy was a shell of *Glycymeris*, a genus previously found only in dredge hauls. Dr. Kay offers perspective on the Palalau mollusks by comparisons with other

Hawaiian locations. The vicinity of Poipu (Kauai), examined variously for more than 20 years, has yielded about 130 species. Sediments from Kealakekua Bay (Hawaii), intensively sampled in 1968, contained 135 species. However, shell abundance at Kealakekua Bay was drastically lower; a little over twice as many specimens (3,107) were contained in more than 2,000 times as much sample volume.

Obviously, Maalaea Bay has a rich and varied molluscan fauna, possibly the greatest number of species of any Hawaiian locality. Similar to the algae, this highly-localized diversity is remarkable, as is the nearshore occurrence of deepwater species. The relative abundance of some uncommon forms (i.e., certain turrids, miters and cones), together with physical characteristics of the Bay, indicate that Maalaea would be an excellent place to study the biologies of such species.

Public Use Values

The beach and nearshore waters of Maalaea Bay have intrinsic values for public recreation and education that are perhaps unequalled elsewhere on the Island. This was recognized in part by the County plan (County of Maui, 1970) in which an extensive shoreline park is proposed. Relevant attributes are:

1. Open, almost continuous sandy beach with immediate public access.
2. Normally low waves for safe entry into the water.
3. Absence of detectable longshore and rip currents.
4. Local seasonal clear water for snorkeling and diving.
5. Diverse flora and fauna for scientific (educational, research) and recreational purposes.
6. Proximity to Maui's population center where good beaches are few.

Wind is objectionable primarily on the beach where it could be reduced by windbreak construction. Board and body surfing are not generally done in the part of Maalaea Bay considered here because of inadequate waves and the incidence of subtidal rock formations. Better surfing conditions exist west of the Palalau subarea.

Aquatic recreational activities may include: swimming, fishing, boating, snorkeling and diving. These would not necessarily occur in the same area and are not all mutually compatible. Snorkeling and diving may also involve collecting of certain animals (shells, fishes) as well as underwater photography. Popularity of this type of photography is increasing and its recreational potential is large, as suggested by the accompanying pictures (Fig. 5). The Palalau subarea is especially good for color photography because of the many corals and other invertebrates that occur in relatively shallow waters that are conducive to good color rendition[6].

Palalau has more value for scientific and certain recreational activities than any other part of this region. Diversity of biota with community differentiation, the presence of uncommon species, physical location and water clarity are features that make Palalau highly desirable for education (at all levels) in marine biology and for the research that must precede it.

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[6]Even in very clear waters deeper than 3 fathoms, actual color is lost rapidly with depth both in perception and in available light photography. This results from differential wavelength absorption by water that ultimately makes everything appear bluish. The reader should note that processing has caused a definite loss of hue and saturation in the photographs comprising Fig. 5 as compared to the color transparencies from which they were made.

DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

The three aquatic systems described here are related in a unidirectional sense. That is, hinterland factors which influence runoff in turn affect the marine ecosystem directly or indirectly via the Kealia Floodplain and its pond. In that manner, Maalaea Bay is the indicator of shoreside activity. Because of its great intrinsic natural value, Maalaea Bay deserves special consideration for protection and preservation to ultimately benefit the public. Such benefit is consequential only through rational public use and enjoyment. To this end, problems, protective measures, and use enhancement are given final consideration.

Land Drainage

The chief problem of land drainage is the discharge of silt during freshet runoff that materially reduces water quality in Maalaea Bay and creates a secondary problem in Kealia Pond, threatening its extinction. This report necessarily ignores the unknown prospect of concomittant toxic and bacterial discharges. Silt discharge is a natural phenomenon evidently enhanced by cultural activities, channel modifications and land development. The first step in abating silt discharge should be to discourage causal activities no matter how distant in the drainage from problem areas.

A second step would consider silt removal from major channels before the discharges reach the problem areas. The possibility of artificial settling basins, from which accumulations could be removed periodically and returned to the land, should be explored. There appears to be adequate area along the principal discharge channels for such engineering development. If silt abatement could be effected, it would not only protect the aquatic ecosystems now endangered, but also improve water quality in eastern Maalaea Bay, thereby enhancing its public use value.

Kealia Floodplain

The unusual feature of Kealia floodplain is that it exists as a large, open natural area along a leeward shore, a prime location for ongoing development in all respects except for windiness. It may not remain that way long. Incipient development has begun--in 1970 as an aquaculture venture and more recently with industrial encroachment (power plant site). The distinctive feature of the floodplain is Kealia Pond, the largest intermittent pond on any of the State's major islands. Two important natural functions of Kealia Pond are its wet-season roles as a sedimentation basin for silt runoff, and as a waterbird habitat. It remains to be seen whether future development will be restricted sufficiently to protect this environment for the benefit of the public.

Intermittency of the pond prohibits a permanent aquatic biota, although high seasonal production of self-colonizing fauna becomes a problem mortality in summer. Keeping the pond flooded, a solution proposed elsewhere, has the serious disadvantage of basin extinction via over-siltation which would in turn destroy the valuable ecosystem of Maalaea Bay. An alternative to wind deflation that now maintains the basin would have to be found.

Creating a permanent waterbird sanctuary of Kealia Pond is a commendable conservation use. Complete refuge development would require perennial water which brings up the silt problem noted above. A technological solution may be possible within the basin. For example, the pond bottom could be dissected by a few dikes low enough to allow generalized settling of freshet-borne silt, but high enough to be exposed at mean water level. The resulting impoundments could be drained alternately and the accumulated silt removed mechanically. If conducted infrequently (i.e., every few years), such operations might not disturb water birds unduly.

A recreational fishery on the floodplain has the highest public use potential in a purely aquatic sense. A simple facility for a seasonal fishery could be attempted on a small part of the pond's basin to take advantage of the winter-spring natural production. It would be necessary only to excavate a small depression, a few acres at most, to a depth of a meter or so to provide a sub-basin retreat for fishes as the pond dries up. This might best be placed along the south central shore (Fig. 2) where fishermen would have easy and controllable access from the highway and where the basin would not tend to foster channelization of the influent streams. This depression would likely become silted with time but could be re-excavated as required. Even if not used for fishing, the sub-basin would facilitate the removal (as by seining) of animals destined to die via desiccation.

An advanced type of recreational fishery with continuous high public use would be the development of natural-appearing ponds with park environs, intensively managed (complete control of water quality and levels, fish stock, disease, predators and competitors) for high-yield angling. Species stocked should be catchable-sized sport fish that are also good table fish. This system would not infringe on the pond basin; construction at a slightly higher elevation (as on the floodplain west of the pond) is optimal. Costs of development and management could be amortized, if desired, by a small user fee (Summerfelt 1968; Stroud 1963, 1965).

Maalaea Bay

Unquestionably, the shoreline is the focus of recreational activity: beaches for sunning, playing and picnicking; waters for swimming, diving and fishing. Its recreational importance mounts with population growth and increasing leisure time. The seashore is also the most desirable area for residential and resort development. Thereby, a conflict arises that must ultimately favor public needs, as noted in the Kihei Civic Development Plan (County of Maui, 1970, p. 47):

> "... As it is the seashore and the ocean that attract people to these communities, so it is the seashore that attracts the highest density urban development, and thus is the most threatened by despoilation. Careless, uncontrolled, short-sighted and dehumanizing urbanization would destroy the natural environment that initially attracted it. Only the most careful planning will assure the preservation and enhancement of this natural environment. As much as possible, the shoreline areas must be preserved, not only for the success of the resort development to come, but to serve the future recreational needs of the entire island."

This eloquent prose applies to the present status of Maalaea Bay but neglects to consider educational and scientific aspects of the Island's needs.

The intrinsic value of that portion of Maalaea Bay characterized previously is unquestioned by those who have examined it. It is essential to protect this ecosystem as a public resource. One has only to read of the deterioration of Kaneohe Bay (Banner and Bailey, 1970) to appreciate the severity of marine environmental degradation by ignored contamination, especially in an area having restricted exchange with the open ocean. Initially, influences that can or might degrade Maalaea Bay should be prohibited. This could be implemented by changing its present water quality status[7] from Class A (which allows pollution under permit) to Class A-A which prohibits such discharges and emphasizes scientific merit and conservation.

Relatively undeveloped and sparsely populated, Maui Island has about 20% of its shoreline waters classified A-A. However, these waters occur in two windward zones that are essentially beachless and have precipitous littoral topography. Furthermore, shoreline access is very restricted and hazardous because of shoreline cliffs and absence of roads. They are zones of doubtful public use and scientific explorability. In fairness to the public and in pursuit of conservation objectives, State regulations should give equal recognition and protection to certain leeward Maui locations that are more diverse ecologically, waters that are unspoiled but inherently more vulnerable to despoilation. Maalaea Bay definitely is one site qualified for such consideration.

A further means of protecting the Maalaea ecosystem should be to establish its waters, or at least the Palalau portion, as a conservation district. This would encourage public appreciation while regulating it to avoid degradation. Perpetuation of this ecosystem also requires a greater understanding of its complexities. Of immediate need are studies to determine current patterns in areal detail and under different meteorological conditions. It is also important to survey the Bay's biota carefully and completely in order to describe fully its ecology and scientific value.

Public use may require restrictions for perpetuating public benefits. Randall (1971) has discussed this matter relative to marine parks, reserves and sanctuaries. Certainly, the Palalau subarea should be set aside for

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[7]Public Health Regulations, Dept. of Health, State of Hawaii- Chapter 37-A: Water Quality Standards.

education, research and non-degrading recreation. The taking or damaging of biota and substrate materials, operation of motors, etc. should be denied. This would ultimately benefit other recreation and public appreciation. For example, Palalau may be a good location for an "underwater trail" (Randall, 1969) which consists of a series of markers directing a snorkeler to inscribed plates that identify individual organisms, colonies, formations, etc. To follow such a trail would not require diving; it would be at once recreational and informative. Public use activities restricted in Palalau could be allowed in the Kaleia subarea.

EPILOGUE

The preceding study was precipitated by proposed commercial-industrial expansion into an undeveloped area--a situation now commonplace throughout the State as both population and economy expand. They are situations of conflict in which conservation opposes exploitation, or protection opposes degradation. Central in these issues are the decisions that must favor one side at the expense of the other--decisions of land rezoning, water classification, and permit application for special use or discharge. Agencies charged with these decisions employ procedures that do not insure adequate environmental evaluation or protection, thereby favoring development. Some use permit applications do not require public hearing. Those that do require hearing allow little time, a few weeks at most, between public notice and decision action. Often, environmental defense is left to a public that is incapable of hastily preparing a cogent defense against development that has been planned professionally over months or even years. Decisions are usually expedited without environmental assessment. Impact statements, even when required, generally are superficial or lacking in expertise.

"Aggressive" conservation inherently embodies more careful considerations than "aggressive" development. The establishment of a Marine Conservation District at Kealakekua Bay, Hawaii is a case in point. In early 1968, it was a relatively undeveloped, obscure location on the Island's west coast, historically notable as the site of Capt. James Cook's demise in 1779. During a period of several months, groups of university scientists, and biologists from the Hawaii Department of Land and Natural Resources (Division of Fish and Game) surveyed the waters and adjoining lands. This survey not only produced data on the natural values of the Bay to justify its establishment as a Conservation District, but also provided guidelines for future development to insure protection of the shoreline and marine ecosystems. Other areas in the State being considered for conservative use are undergoing similar long-term study.

Contrast the above instance with the "aggressive" development of Kealia-Maalaea. No environmental assessment preceded the proposal to dredge a medium-draft harbor. Neither of the developments now established on the floodplain (aquaculture, powerplant) evaluated the ecosystems before they had applied for rezoning or use permit. It is to the credit of the County Planning and State Land Use Commissions that power generation by steam turbine (necessitating massive discharge of heated water) was deferred until an environmental study could be accomplished.

Obviously, not every instance of proposed development or discharge requires intensive ecosystem evaluation. In cases where study is necessary, time becomes an important factor. If months or years are needed to plan an extensive development, then sufficient time should be allowed for ecosystem analysis. Present procedures should be modified to recognize this need, possibly by declaring a moratorium on decisions in temporal proportion to the size and ecological complexity of the area affected by proposed development. Ecosystem appraisal must be done by individuals with competence and objectivity. If these needs are recognized, then a responsible agency within the State administration must be charged with insuring their accomplishment and judging their adequacy.

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Appendix Table 1. Checklist of benthic algal genera from 3 transects in Maalaea Bay, Maui (cf., Fig. 4) July 1971.*

Genus	Number of species	Genus	Number of species
Division Cyanophyta		Division Rhodophyta	
Calothrix	1	*Acanthophora*	1
Microcoleus	1	*Actinotrichia*	1
		Amansia	1
Division Chlorophyta		*Amphiroa*	1
Boodlea	1	*Ahnfeltia*	1
Cladophora	1	*Asparagopsis*	1
Cladophoropsis	1	*Champia*	1
Codium	4	*Corallina*	1
Dictyosphaeria	2	*Crouania*	1
Enteromorpha	1	*Desmia*	1
Halimeda	1	*Galaxaura*	1
Microdictyon	1	*Gelidium*	1
Ulva	3	*Gracilaria*	1
Valonia	1	*Grateloupia*	2
		Halymenia	1
Division Phaeophyta		*Hemitrema*	1
Chnoospora	1	*Herpophyllon*	1
Colpomenia	1	*Hypnea*	2
Dictyopteris	1	*Jania*	1
Dictyota	3	*Laurencia*	1
Ectocarpus	2	*Liagora*	1
Hydroclathrus	1	*Peyssonelia*	1
Padina	2	*Porolithon*	1
Sargassum	1	*Spyridia*	1
Sphacelaria	1	*Trichogloea*	1
Turbinaria	1		

*Species list available from Hawaii Inst. Marine Biol., P.O. Box 1067, Kaneohe, Hawaii 96744.

Appendix Table 2. Mollusks from beachdrift, intertidal beachrock, and nearshore sediments of Palalau subarea, Maalaea Bay, Maui. The families observed with numbers of genera and species identified in each.*

Family	Number		Family	Number	
	Genera	Species		Genera	Species
Gastropoda			Muricidae	3	3
Fissurellidae	1	2	Columbellidae	4	8
Trochidae	3	5	Buccinidae	1	1
Turbinidae	1	3	Fasciolariidae	1	1
Phasianellidae	1	1	Nassariidae	1	1
Neritidae	2	2	Marginellidae	3	3
Littorinidae	2	2	Mitridae	2	6
Rissoidae	6	13	Turridae	6	11
Vitrinellidae	2	2	Conidae	1	1
Risoellidae	1	1	Pyramidellidae	3	9
Architectonicidae	1	2	Atyidae	2	2
Vermetidae	2	2	Hydatinidae	3	3
Caecidae	2	3	Aceteocinidae	1	1
Diastomidae	4	6	Siphonariidae	2	2
Cerithiidae	3	11			
Cerithiopsidae	1	4	Bivalvia		
Triphoridae	1	20	Arcidae	1	1
Epitoniidae	2	4	Limopsidae	1	1
Eulimidae	1	3	Glycymeridae	1	1
Vanikoridae	1	1	Mytilidae	1	1
Hipponicidae	2	2	Pectinidae	1	1
Calyptraeidae	1	1	Limidae	1	2
Cypraeidae	1	4	Pteriidae	1	1
Eratoidae	2	4	Lucinidae	2	2
Cymatiidae	1	1	Condylocardiidae	1	1
Naticidae	1	2	Mesodesmatidae	1	1

*Species list available from Hawaii Inst. Marine Biol., P.O. Box 1067, Kaneohe, Hawaii 96744.