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POSSIBLE ENVIRONMENTAL IMPACT OF IMPORTING ANCHOVY INTO HAWAII

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The Hawaiian fishery for skipjack tuna, *Katsuwonus pelamis*, with an average annual ex-vessel value in excess of $2 million, experiences considerable fluctuations in landings from year to year. The annual landings average around 9 million pounds but fluctuate between 5 and 16 million pounds. This fluctuation has several causes, one being the shortage of live bait. Essentially, any small fish will serve as bait and the effectiveness varies from species to species. Hawaiian skipjack tuna fishermen, by far, prefer nehu, *Stolephorus purpureus*, a small (40-60 mm), fragile anchovy that schools in bays and harbors of the Hawaiian Islands. The seasonal availability of nehu varies greatly, but in general, the supply is insufficient to allow maximum fishing effort by the existing fleet. The problem with the bait supply is particularly serious during the peak skipjack tuna fishing season, from around May to September, when many of the boats spend considerable time obtaining the bait needed to fish skipjack tuna. Obviously, if the boats could fish skipjack tuna instead of spending so much time catching bait, the landings of the Hawaiian fishery would increase proportionately. Furthermore, the nehu are extremely delicate, and do not survive in the baitwells for more than a few days. This factor greatly limits the range of the fishing boats. A solution to the baitfish problem, which would replace time used to catch bait with additional fishing time, could increase the annual catch of skipjack tuna by as much as 66% and provide for an increase in ex-vessel value of the catch of $1.9 million. It should be pointed out that this increase would occur with the existing fleet; any expansion of fleet size would provide for added incremental growth since available evidence indicates that the skipjack tuna resource is underutilized and could withstand additional fishing pressure.

Various solutions to the baitfish problem have been proposed and researched in the past. The culture of live bait has been tried and found to be either too expensive or the cultured baitfish has been unacceptable to the fishermen. Another approach has been the development of artificial bait, e.g., various types of odor-impregnated food pellets. All of these were found to be ineffective.

One of the most direct and feasible approach to the problem is to bring in a supply of baitfish from areas where they are readily available. In the case of Hawaii, the northern anchovy, Engraulis mordax (Figure 1), from California seems a good possibility. The northern anchovy has been transported to Hawaii in the past on several occasions, mostly on an opportunistic basis and in small quantities. All indications are that this species is hardier than the nehu and would allow the Hawaiian tuna boats to range farther from base port than is now possible with the nehu. Because of the lower mortality to be expected with the northern anchovy, the catch per unit of bait carried to sea should increase substantially. The northern anchovy has been used successfully in fishing for skipjack tuna in the central Pacific. Further, it is one of the principal baitfish used by the tuna bait boats in the eastern Pacific.

The main thrust of our program, then, is to develop the technology needed for the transportation, holding and ancillary requirements to the successful importation of live northern anchovy from California to Hawaii.

Briefly, the activities of this program will be conducted in four phases. Phase 1 will encompass a preliminary review and assessment of various baitfish transport alternatives. Phase 2 will test the feasibility of transporting live bait using the alternative assessed to be most promising. Phase 3 involves the development of a full-scale system of economically transporting bait to Hawaii on a sustaining basis--a system that would supply all of the baitfish needs of the Hawaiian fleet. Phase 4 will comprise report writing.

One of the most serious possible environmental impacts of the program is that the northern anchovy may become established in Hawaiian waters to the detriment of the endemic Hawaiian marine fauna. During the course of various activities of the program northern anchovies will most certainly, whether inadvertently or purposefully, be released in Hawaiian waters. Opportunities to escape will be numerous, e.g., when the anchovies are being held in holding enclosures and when they are being transferred from holding facilities to fishing boats. They will also be deliberately released into the environment when they are chummed as live bait in fishing operations. However, whether or not they will become established in Hawaiian waters as a consequence of the escape of some individuals is difficult to ascertain with any certainty. Knowledge of the biology of the northern anchovy, however, should provide some clues as to the probability of its establishment in Hawaiian waters, and as to whether its establishment will be detrimental to the Hawaiian fauna.

The northern anchovy is a temperate water species which is found off the coast of North America from the Queen Charlotte Islands, British Columbia to Cape San Lucas, Baja California (Figure 2). They are pelagic schooling fishes and are most common in coastal waters between San Francisco and Magdalena Bay, Baja California. They are ordinarily found in water ranging from 14.6°C (58.2°F) to 20.0°C (68°F) although in the extreme they have been found in water as cool as 5°C (41°F) and as warm as 25°C (77°F). The salinity of the water they occur in range from <32.5‰ to >34.5‰.

In certain seasons of the year, usually in the summer and fall, large compact schools of northern anchovy are found during the day along submarine escarpments and canyons at depths of 110 m (360 ft) to 183 m (600 ft). During hours of darkness the schools rise to the surface and the anchovies disperse. They start to re-form into compact schools and return to deeper water with the coming of dawn.

Northern anchovies begin to reach sexual maturity at the end of their first year of life when they are about 10.2 cm (4 inches) to 11.4 cm (4.5 inches) long. Almost all anchovies are fully mature when they are 2 years old and are 12.7 cm (5 inches) to 14.0 cm (5.5 inches) long. It is estimated that female anchovies can spawn from 4,025 to 21,297 eggs per spawning. Northern anchovies usually spawn within 60 miles of the coast. However, anchovy eggs have been found as far offshore as 300 miles. The eggs and larvae of anchovies are pelagic.

Northern anchovies spawn throughout the year, particularly in the southern portion of its range. There is a peak in spawning activity in the late winter and spring. Most of the pelagic anchovy eggs have been found in water with temperatures between 13.0°C (55.4°F) and 17.5°C (63.5°F). The threshold temperature for anchovy spawning is believed to be about 11.5°C (52.7°F) or 12.0°C (53.6°F).

The northern anchovy seldom lives over 4 years. They apparently are filter feeders, indiscriminatingly accepting zooplankton or phytoplankton. They have also been found to have small fish in their stomachs. With regard to food, they are direct competitors of the Pacific sardine, Sardinops caeruleus. They also compete with the Pacific sardine for space since both species are found in greatest abundance between Point Conception, California and Magdalena Bay, Baja California. A great number of fishes, birds, and mammals prey on the northern anchovy. Studies have indicated that the northern anchovy is probably the most important forage species in the inshore waters of California and Baja California. Certainly, the northern anchovy is important in the diet of all the large predatory game fish off California.

Whether northern anchovies may become established in Hawaiian waters will depend to a great degree on how successfully they can adapt to the temperature of the water surrounding the Hawaiian Islands. It is believed that one of the primary limiting factors in the distribution of northern anchovy, and indeed most of the species in the genus Engraulis, is water temperature. Generally, fishes in the genus Engraulis have not been found either in the coldest or warmest oceanic conditions. It is estimated that a range of temperature from 6°C (42.8°F) to 23°C (73.4°F) would include nearly all of its occurrences. We noted that the northern anchovy was usually found in water ranging from 14.6°C (58.2°F) to 20.0°C (68°F). The Hawaiian oceanographic climate, as represented by observations made at Koko Head, Oahu, includes extremes in range of temperature from 22.5°C (72.5°F) in February or March to 27.4°C (81.3°F) in September or October. These observations suggest that the Hawaiian oceanic environment, insofar as temperature is concerned, is not suitable for the northern anchovy. Granted, past experience has shown that live northern anchovy do survive the change in temperature from that found in California waters to that found in Hawaiian waters. But whether they can adapt to these temperatures on a long term and form a viable, reproducing population, i.e., become established, is another matter. Certainly one important factor is the observation on the threshold temperature for anchovy spawning. The water temperature around Hawaii does not get low enough to reach the threshold value required for anchovy spawning.

The salinity values found around Hawaii, again as represented by observations made at Koko Head, Oahu, are within the range the northern anchovy is found in off the west coast of North America. The extremes in salinity observed at Koko Head range from about 34.4‰ in July to 35.5‰ in late fall or early winter. The salinity range is greater in more estuarine conditions. For example, in Kaneohe Bay, Oahu, the annual range in salinity is from 31‰ to 36‰. We noted that northern anchovies were found in waters with salinity ranging from <32.5‰ to >34.5‰. It is believed that the species in the genus Engraulis in general are not limited by salinity values encountered in the ocean or estuaries. They have been found in water ranging from 2‰ to 39.4‰ in salinity.

To summarize what is known about conditions limiting the distribution of the northern anchovy to this point, it has been indicated that salinity is not limiting but temperature most likely is. However, it has also been shown that there are vast areas of ocean habitats with suitable temperature that do not support *Engraulis* populations. This suggests that there are other factors besides salinity and temperature that are important to *Engraulis*, including the northern anchovy. Because *Engraulis* is a coastal genus, i.e., although their eggs and larvae are sometimes found far offshore, they are definitely tied to a coastal population; some scientists believe that coasts are essential to *Engraulis*. If this observation is correct, then the lack of an extensive coastline in Hawaii will be a negative factor in the possible establishment of the northern anchovy in Hawaiian waters.

Evidence supporting the observation that Hawaii's oceanographic environment may not be conducive to the establishment of the northern anchovy may be found in past experiences with this species. In 1932, a release of 6,000 northern anchovy was made in Kaneohe Bay, Oahu. The anchovies were part of a load of live bait transported from California to Hawaii by a California tuna clipper. These anchovies did not survive and no reproducing population was established from this introduction. Although not well documented, there have been other inadvertent or purposeful releases of northern anchovies in Hawaiian waters, but, this species has not become established from these releases.

It should be pointed out that the number of individuals introduced may be crucial in determining the success of the establishment of a species, especially in a marine environment. The experience in the establishment of the Marquesan sardine, *Sardinella marquesensis*, in Hawaii indicated that those releases with 20,000 or more individuals were important in their establishment while those of 10,000 or less were not. Our program of importing northern anchovy will *not* be with the idea of trying to establish them in Hawaii. Numbers of northern anchovy will surely escape confinement. They would also be successful, to some unknown degree, in escaping their predators after being chummed as bait. However, the numbers surviving such accidental or purposeful releases should be minimal and certainly not in quantities favorable to their establishment.

Up to this point we have discussed the factors that would or would not be conducive to the establishment of northern anchovy in Hawaii. We can conclude from the evidence that the chances are virtually nil that northern anchovy can become established as a consequence of our program. However, the possibility exists, howsoever small, that they may become established. What would then be the consequences of the establishment of northern anchovy in Hawaiian waters? The most undesirable consequence would be that they would compete with native Hawaiian species for food and space to the detriment of the native fishes. Some of the species that the northern anchovy may possibly compete with are the nehu, the akule or bigeye scad, *Trachurops crumenophthalmus* and the opelu or mackerel scad, *Decapterus pinnulatus*.

The nehu, akule, and opelu appear to be primarily zooplankton feeders (Tables 1 and 2). Although food studies on the northern anchovy are not plentiful, it appears that the northern anchovy is slightly lower on the trophic scale than nehu, akule, and opelu. We noted that they indiscriminately fed on zooplankton and also phytoplankton. While studies on this subject is lacking, akule and opelu probably exercise some selection in their feeding. There is some evidence to indicate that the nehu prefers the crustacean components of the zooplankton, at least in some areas of their habitat. Thus, although the northern anchovy may compete somewhat with nehu, akule, and opelu for food in that part of its diet that includes zooplankton, it does not directly compete in the sense that it is not a selective feeder.

The northern anchovy will no doubt compete for space with opelu and akule if they become established in Hawaiian waters. It is difficult to assess the consequences of this type of competition. Off the coast of California, however, the Pacific sardine is considered the chief competitor of the northern anchovy. Discounting the effects of the fishery on the Pacific sardine, there is no clear evidence that the Pacific sardine has not been able to compete successfully with the northern anchovy for space and food. Other similar species off the California coast apparently compete with the northern anchovy and with each other presumably without any deleterious effects. There is no reason to believe that the akule and the opelu will not be able to compete successfully with the northern anchovy in the Hawaiian environment.

The northern anchovy will probably not compete with the nehu for space. Ecologically, the nehu is restricted more to sheltered coastal waters and estuaries whereas the northern anchovy is more pelagic. The nehu spawns in sheltered bays and harbors whereas the eggs and larvae of the northern anchovies are pelagic.

Other possible environmental impacts of the program are the possibility of the transfer of disease with the northern anchovy and the inadvertent introduction of other species of fish together in the shipments of northern anchovy. Very little is known about diseases in populations of pelagic marine fishes. However, as a precautionary measure all shipments of northern anchovy will be treated with appropriate chemicals (e.g., copper sulfate) to reduce the possibility of the introduction of diseases. Furthermore, specimens from trial shipments will be subjected to critical examination by a fish pathologist to insure that the anchovies are disease free. The chances that other species of fish will be mixed with the shipment are considered to be small. However, even if small numbers are mixed with the northern anchovies, the chances that these temperate water species will survive and become established are even less than for the anchovy for reasons already elaborated.

Although we have so far discussed only the unwelcome consequences of the establishment of the northern anchovy in Hawaii there may be some beneficial results. It was noted that the northern anchovy was an important item in the diet of all the large predators in the inshore waters off California. In the forage poor waters of Hawaii the northern anchovy may be a welcome addition to the diet of Hawaiian predator fishes. Indeed, they may act to attract larger numbers of commercially important fishes like the tunas and billfishes to Hawaiian waters. It has been noted in California that the number of Pacific bonito, *Sarda chiliensis*, taken by California party boats has increased greatly concurrent with the growth of the northern anchovy population. More obviously, the establishment of the northern anchovy may be another source of live bait for the Hawaiian skipjack tuna fishermen and may form the basis of a new fishery for bait similar to the California bait fishery.

In summary, we have indicated several conditions that make the chances of the establishment of the northern anchovy in Hawaiian waters highly unlikely: the lack of suitable temperatures in general; and more important, the lack of suitable temperatures to trigger anchovy spawning; and finally the possible importance of extensive coastlines, which Hawaii lacks to support an anchovy population. We have also pointed out that the establishment of an anchovy population in Hawaiian waters will probably not have a deleterious effect with regard to the Hawaiian fauna. Finally, we have suggested possible benefits of the establishment of an anchovy population in that it will provide much needed forage for Hawaiian predator species, provide bait for the Hawaiian skipjack tuna fishermen, and may also form the basis of another fishery.

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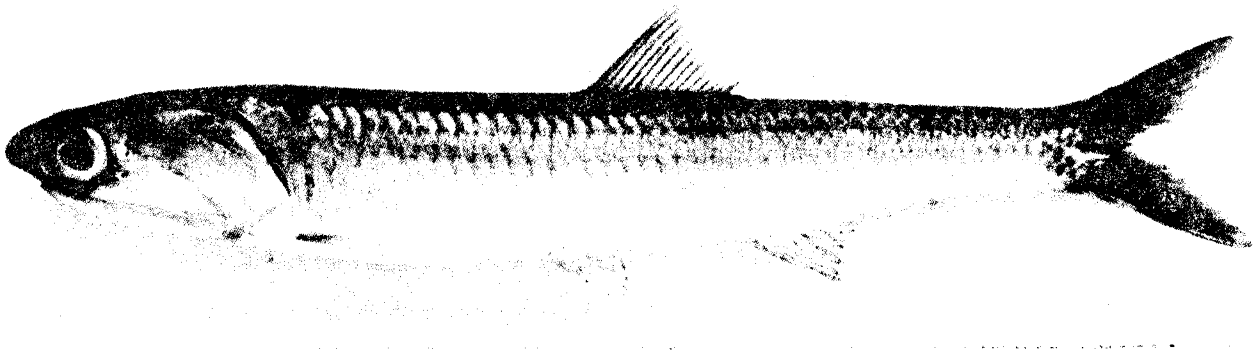

Figure 1.--Northern anchovy, Engraulis mordax. (From Frey 1971.)

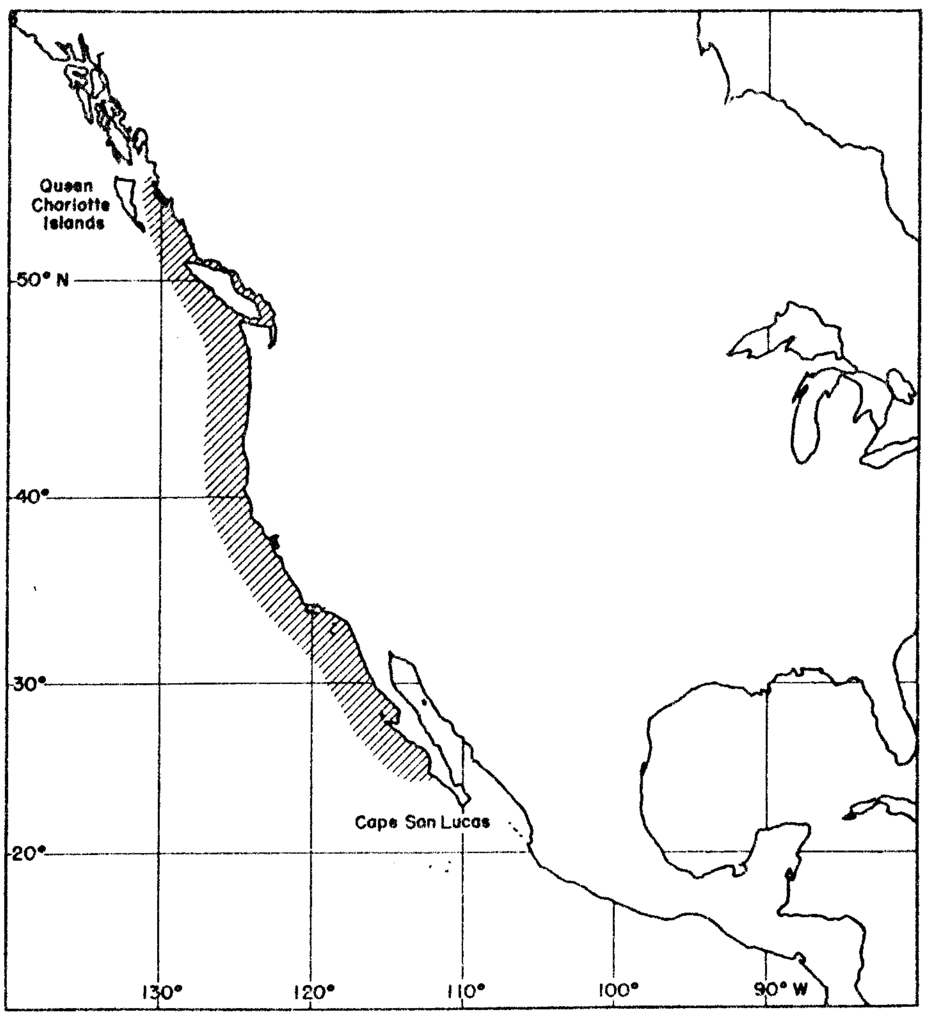

Figure 2.--The distribution of northern anchovy, Engraulis mordax, off the coast of North America. (Adapted from Reid 1967.)

Table 1.--Food of nehu, *Stolephorus purpureus*, in Kaneohe Bay, Oahu, based on an analysis of 80 stomachs. (From Hiatt 1951:Table 2.)

Organism	Percentage frequency of occurrence among fish examined	Average number taken per fish containing the item	Percentage composition of food items based on total number of organisms found in the stomachs
Copepods			
Adults	79	16	35
Eggs	30	23	19
Shrimps			
Adults	6	1	Trace
Mysis	29	19	15
Zoeae	5	11	1
Barnacle larvae			
Nauplii	25	20	13
Cypris	25	7	5
Crab zoeae	25	12	8
Amphipods (Hyperiidae)	11	7	2
Ghost shrimps, *Leucifer faxonii*	11	2	1
Isopods	4	2	Trace
Gastropod veliger Larvae	1	1	Trace
Ostracods	1	2	Trace
Stomatopod larvae	1	8	Trace
Fish larvae	1	3	Trace
Diatoms	3	4	Trace

Table 2.--Food of opelu. Stomach analyses of 24 opelu taken off Brown's Camp, Oahu, May 3, 1951. (From Yamaguchi 1953:Table 7.)

No.	Length cm	Sex	Copepod	Amphipod (Hyperiidae)	Euphausiidae	Ghost shrimp (Leucifer)	Shrimp	Crustacean larvae	Crab megalopa	Pelecypod mollusc larvae	Stomatopod larvae	Chaetognatha (Sagitta)	Fish larvae	Fish scales
1	26.0	M	2	18					8	1			1	
2	23.5	F		12		4	2	7	14					
3	22.5	M	13	14	5			6	2	2	2	3		x
4	21.6	M		6	2		3	2	10	2			3	
5	21.5	M		26		6		10	11			2	1	
6	23.0	F	5	4	4	3	1		3	3				
7	25.2	F	3	10				3	2	1	1	1		x
8	23.4	M	3	16					12			4		
9	24.1	M		5	6	2	3	2	3				1	
10	25.0	F	10	16	3	1	2		8	1			2	
11	21.8	M		20			5	12	17	2		2	1	x
12	23.0	M	2	12	1	5	6		10		4		1	x
13	26.8	F	13	22		5	2		3		1			
14	21.0	M		8	2	2	3		21	2	2			
15	22.4	F		2		1	1	6	4		1		2	
16	23.6	M	9	10				6	4	1		4		x
17	21.5	M		8	3		4		3		3	1	3	
18	21.8	M	4		3	1	7	4	11	3	2	2		
19	23.7	M	16	16		2	4		13			1	1	
20	21.9	F	2	29	5	2	2		2					
21	24.0	M	2	5	3		2	7	5		1			
22	23.3	F		6		8	5		22	1		1	1	x
23	22.5	M		18		2	2	12	12		3	3	2	
24	21.8	M	18	7	2	3			10			1	1	
			102	290	39	47	54	77	210	19	20	25	23	