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Energy constraints may put distant-water trawl fleets on a short leash.

Energy Efficiency Comparison between the Washington and Japanese Otter Trawl Fisheries of the Northeast Pacific

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It is well known that the large, mothership-based trawlers from foreign nations, principally Japan and the USSR, fishing in the northeastern Pacific Ocean are more efficient than the smaller U.S. trawlers operating in parts of the same waters in terms of traditional units of efficiency, such as pounds landed per trawling hour.

In fact, much concern has been expressed not only by the west coast U.S. fishery industry but elsewhere in the world—that fleets of large, distant-water trawlers will outcompete and therefore displace fleets of smaller, home-based fishing vessels because of their greater efficiency.

To compare these two so different types of fishing operations we undertook an analysis of the Washington State and the Japanese otter trawl fisheries of the northeast Pacific, taking as our principal parameter for comparison the ratio of outputs of edible fishery products to inputs of manpower, materials, and fuel (all converted to energy equivalents):

$$\text{Efficiency} = \frac{\text{kcal food output}}{\text{kcal input}}$$

Energy output:input analysis is receiving increasing attention in studies of agricultural systems (Pimentel et al., 1973 and Steinhart and Steinhart, 1974) and a great many other industries (Herendeen, 1973) as global concerns for decreasing supplies of nonrenewable fuels intensify.

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THE FISHERIES

The Washington trawl fishery, which is about 60 years old, is presently composed of 81 (1971-72 average) licensed vessels, of which about 30 operate as full-time trawlers which fish the waters of the continental shelf from the Columbia River mouth to northern British Columbia. The average trawler in this fleet is 80 feet in length and weighs 86 gross tons. Hulls are generally of steel (wood in older boats) and the engine is typically a 300-hp diesel. The length of stay on the fishing grounds varies from single-day trips to a maximum of about 14 days. Other than separating and icing the catch, no processing is done aboard. The data for the present analysis are from 11 full-time trawlers which operated during 1971 and 1972 and for which annual fuel consumption and landing figures were available.

The segment of the Japanese trawl fishery selected for comparison consisted of 32 mothership-based stern trawlers which operated along the continental shelf region of the Gulf of Alaska in 1972[1]. Commercial Japanese trawling in this area of the northeast Pacific began in 1965. Typically these vessels are on the grounds for several months at a time, unloading their catches periodically to the motherships wherein processing takes place. The geographical center of operation of the Japanese vessels is north of that of the Washington fleet, but there is overlap in fishing grounds between the two. The Japanese trawlers ranged in size from 345 to 5,460 gross tons, with an average of 1,947. Hulls are of steel and the diesel engines used range in power from 850 to 5,700 hp.

[1]There were 42 vessels licensed to fish these waters in 1971 and 1972, but only 32 actually fished.

Table 1 compares the physical specifications for vessels in the two fleets. The average fuel consumption figures need further discussion. For the Washington fleet, they are based on specific consumption figures for 11 vessels furnished by the fuel supplier. For the Japanese fleet, no such reliable figures were available. Thus, we had to rely on estimates of fuel consumption for vessels in their general horsepower range (Table 2). The average fuel consumption (Japanese vessel) from four separate estimates was 1.49 gal per horsepower-day with an average of 2,648 horsepower per vessel and 205 operating days per year per vessel; we estimated the annual fuel consumption per vessel to be 808,832 gal. The assumed 205 fishing days used for the Japanese trawlers, which is the same as Washington trawlers, is probably minimal because of the additional running time of the Japanese vessels to and from the fishing grounds.

The total catches for both fisheries are listed by species in Table 3. Pacific ocean perch make up the bulk of the Japanese catch, with pollock and black

Table 1.—Average specifications for 11 Washington and 32 Japanese otter trawlers operating in the Northeastern Pacific, 1971-1972.

	Washington trawlers	Japanese trawlers
Vessel length	80 ft[1]	Not available
Hull material	steel	steel
Gross tonnage	[1]86	[2]1,947
Type of vessel	stern trawl	stern trawl
Horsepower of engine	[1]300	[2]2,648
Crew size	4 men[1]	67 men[2]
Annual days away from port	205	205
Trawl head rope length	82 ft[1]	163 ft[2]
Trawl ground rope length	96 ft[1]	226 ft[2]
Mesh size—cod end	3.5 inches[1]	3.6 inches[2]
Annual landings round weight	990,831 lb per vessel[3]	5,378,189 lb per vessel[4]
Annual diesel fuel consumption[5]	27,107 gal per vessel	808,832 gal per vessel

[1]Pattie, B. and G. DiDonato. Washington Department of Fisheries, Seattle, Wash. Pers. Commun.
[2]International North Pacific Fisheries Commission, unpublished documents and records supplied by K. Mimura, Research and Development Dept., Fishery Agency of Japan, Tokyo.
[3]Ward, D. Washington Department of Fisheries, Olympia, Wash. Pers. Commun.
[4]Average pounds landed per Japanese vessel is catch by total fleet (Table 3) divided by 32 (number of vessels).
[5]Fuel consumption figures are discussed in text and Table 2.

Table 2.—Estimated diesel fuel consumption by Japanese trawlers.

Gallons per horsepower-day	Source and method of computation
1.41	According to Henry Shek, marine engineer with NOAA (Seattle, Wash.), a vessel in the horsepower range of the Japanese trawlers consumes about 0.425-lb fuel per horsepower hour. Diesel fuel weighs about 7.24 lb per gallon and a continuous 24 hours per day operation was assumed.
1.55	Robert French, in charge of the U.S. National Marine Fisheries Service, NOAA foreign trawl observer program, (Seattle, Wash.) reported that one of his technicians aboard a 5,900-ton Japanese trawler in the Bering Sea observed a daily fuel usage of 30 metric tons.
1.21	Labberton and Marks (1945) reported that an efficient, 4,000 hp diesel vessel consumed fuel at a rate equivalent to 4,840 gal per 24-hour day.
1.80	A representative of a Seattle-based marine fuel distributor estimated that U.S. king crab vessels of about 1,000 hp (the largest U.S. commercial fishing vessels operating in the northeastern Pacific) consume 70-80 gal of diesel fuel per hour, or about 1,800 gal per 24-hour day of continuous operation.
Mean 1.49	

Table 3.—Annual catches in pounds round weight by the Washington and Japanese otter trawl fisheries in the north Pacific, 1971-1972 average.

Species	Washington fishery	Japanese fishery
Green sturgeon	13,726	—
Butter sole	1,610	—
Dover sole	1,284,093	—
English sole	2,056,306	—
Petrale sole	1,419,681	—
Rex sole	79,629	—
Rock sole	561,587	—
Sand sole	174,012	—
Sanddab	70	—
Starry flounder	638,201	—
Turbot	36,877	—
Black cod	103,990	14,033,000
Lingcod	1,732,733	—
Pacific cod	7,479,742	1,317,000
Pollock	70,376	23,760,000
Hake	7,375,238	1,992,000
Rockfish	10,603,415	4,497,000
Pacific ocean perch	8,398,557	109,378,000
Blue sea perch	251	—
White sea perch	3,688	—
Ratfish	33,854	—
Dogfish	31,380	—
Skate	15,141	—
Octopus	22,072	—
Squid	2,243	—
Shad	245	—
Mackerel	21	—
Miscellaneous	523,144	17,125,000
Total	42,661,882	172,102,000

Sources: Washington catches are from the Washington Department of Fisheries annual catch statistics, unpublished but available in bound volumes in Olympia, Wash., and furnished by Dale Ward of that Department. Japanese catches are from unpublished records of the International North Pacific Fishery Commission, obtained from their central office in Vancouver, B.C.

Table 4.—Energy requirements to build a steel-hulled fishing vessel of approximately 200 gross tons.

Item of input	Kcal
5,000 8-hr man days @ 3,110 kcal/day	15,550,000
100,000 kw-hr electrical power @ 860 kcal/kw-hr	86,000,000
230 tons steel @ 1.7 × 10⁷ kcal/ton	3,910,000,000
35,000 ft³ natural gas @ 260 kcal/ft³	9,100,000
114,192 ft³ oxygen @ 260 kcal/ft³	29,690,000
29,250 ft³ acetylene @ 260 kcal/ft³	7,605,000
Total	4,057,945,000
Input per gross ton	20.259×10^6

Sources: Items of input, personal communication with Puget Sound shipbuilding firm; conversion factor kw-hr to kcal (Labberton, 1945): conversion factors steel, natural gas, oxygen, and acetylene (Steinhart and Steinhart, 1974).

Table 5.—Annual energy inputs for Washington and Japanese trawlers operating in the northeastern Pacific.

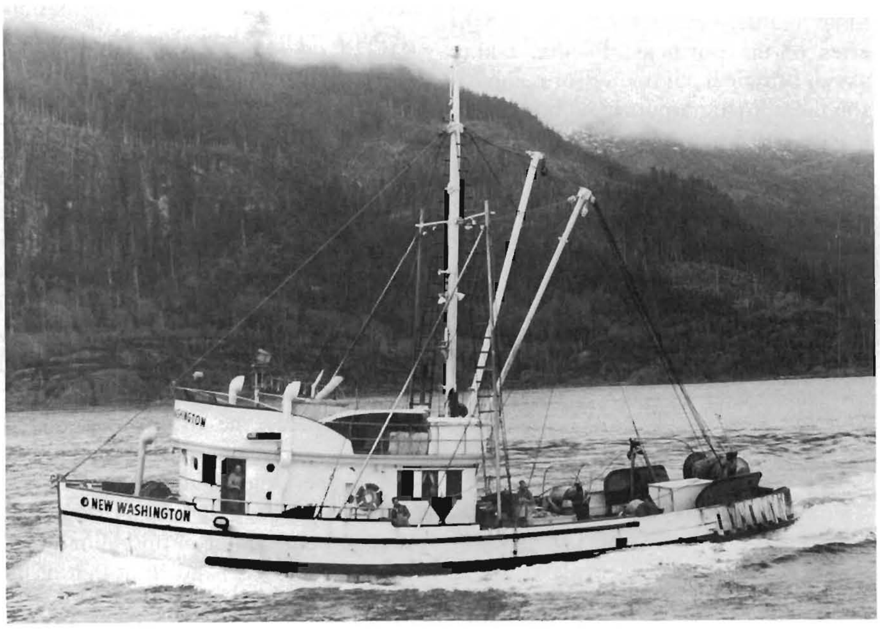
	Washington trawler	Japanese trawler
Fuel energy (34,650 kcal/gal × gal/yr)	939×10^6 kcal	$28,026 \times 10^6$ kcal
Manpower energy (3,110 kcal/man day × crew size × 205 days)	3×10^6	43×10^6
Vessel construction (1.014×10^6 kcal/gross ton/year × average gross tons)	87×10^6	$1,974 \times 10^6$
Total energy	$1,029 \times 10^6$ kcal	$30,043 \times 10^6$ kcal

cod, species not especially sought by the Washington trawlers, making up important segments of the catch. The Washington catch is more diversified, but the principal fish are Pacific ocean perch, rockfish of several species, Pacific cod, and soles and flounders of several species.

ENERGY INPUTS

The principal energy inputs are diesel fuel, manpower, and materials for vessel construction. Conversion of annual fuel and manpower inputs to kilogram-calories was relatively straightforward; a working man requires approximately 3,110 kcal per day (Pimentel, et al., 1973). A gallon of diesel fuel contains 34,650 kcal of energy (Hougen, et al., 1959). Additional energy required to refine diesel fuel from petroleum is only a small fraction of the amount contained in the product (less than one-fortieth (Stanford Research Institute, 1972)); so this was ignored. The estimate of energy requirements in vessel construction was derived from information furnished by a Puget Sound boat yard on the inputs required to build a 200-gross ton, steel-hulled fishing vessel (Table 4)[2]. For this vessel, 20.289×10^6 kcal per gross ton were required. We estimated the fishable life of a steel-hulled vessel to be 20 years; consequently, the annual energy input per year per gross

[2]We are indebted to Lee Morgan, College of Fisheries, University of Washington, Seattle, who computed this information from the boat yard records, and to the boat yard naval architect, who made the records available.



Washington State trawler.

ton of vessel was estimated to be one-twentieth the total input value, or 1.014×10^6 kcal.

The annual energy inputs per vessel are computed in Table 5. An average Washington trawler requires $1,029 \times 10^6$ kcal per year. A Japanese trawler requires $30,043 \times 10^6$ kcal per year. The principal item of energy input is fuel, representing over 90 percent of the total energy requirements for both fleets.

ENERGY OUTPUTS

Pounds of fish were converted to kilogram-calories of consumable food by the percent of total round weight that is edible for each species and the percentages of the edible portions that are fat and protein (Table 6), and the conversion factors of protein and fat weight to kilogram-calories (1 gram protein = 4.2 kcal and 1 gram fat = 9.5 kcal) (Borgstrom, 1968). Computed on this species by species basis, the annual output in terms of food energy in the edible flesh is $8,180 \times 10^6$ kcal for the Washington fishery and $39,808 \times 10^6$ kcal for the Japanese fishery. Based upon the poundages in Table 3, the energy equivalents per pound of round weight landed are:

Washington fleet - 171 kcal/lb
Japanese fleet - 231 kcal/lb.

Table 6.—Maximum yields[1] and proximate compositions of fish.

Species	Percent edible flesh: round weight	protein	fat
Green sturgeon (*Acipenser medirostris*)	50.0	16.0	10.0
Butter sole (*Isopsetta isolepis*)	49.3	17.1	1.1
Dover sole (*Microstomus pacificus*)	47.9	15.2	0.8
English sole (*Parophrys vetulus*)	60.2	17.0	1.6
Petrale sole (*Eopsetta jordani*)	62.9	18.2	1.5
Rex sole (*Glyptocephalus zachirus*)	49.4	16.6	0.7
Rock sole (*Lepidopsetta bilineata*)	47.7	18.3	0.7
Sand sole (*Psettichthys melanostictus*)	61.0	17.2	0.5
Sanddab (*Citharichthys sordidus*)	60.2	17.0	1.6
Flounder (*Platichthys stellatus*)	47.9	17.1	1.1
Turbot (*Atheresthes stomias*)	59.1	17.9	2.4
Miscellaneous	49.8	18.0	1.1
Black cod (*Anoplopoma fimbria*)	62.8	12.9	15.2
Lingcod (*Ophiodon elongatus*)	47.0	17.7	1.0
Pacific cod (*Gadus macrocephalus*)	37.8	17.9	0.6
Pollock (*Theragra chalcogramma*)	35.0	16.0	2.0
Hake (*Merluccius productus*)	49.0	16.1	2.5
Rockfish (*Sebastodes* sp.)	46.5	19.0	1.5
Pacific ocean perch (*Sebastodes alutus*)	50.2	19.2	1.5
Blue perch (*Embiotoca jacksoni*)	40.0	17.5	2.0
White seaperch (*Phanerodon furcatus*)	40.0	17.5	2.0
Ratfish (*Hydrolagus colliei*)	36.9	14.0	10.0
Dogfish (*Squalus acanthias*)	36.9	15.0	13.0
Skate (Rajidae)	50.0	16.0	6.0
Octopus (*Polypus hongkongenis*)	59.0	19.0	0.8
Squid (*Loligo opalescens*)	59.8	19.3	0.7
Shad (*Alosa sapidissma*)	60.0	18.7	9.8
Mackerel (Scombridae)	45.0	19.0	11.0

[1]All yields are based on what could be obtained from whole fish using flesh separating machine (Miyauchi and Steinberg, 1970).
Sources: Values obtained by considering data from a wide variety of sources: (Miyauchi and Steinberg, 1970; Thurston, 1961a, 1961b, and 1961c; Patashnik et al., 1970; and Dan Sortwell, John Dassow, and Richard Nelson, Pacific Fishery Products Technology Center, National Marine Fisheries Service, NOAA, Seattle, pers. commun.)

EFFICIENCY

Energy output:input ratios per trawler for the 11 Washington and 32 Japanese trawlers were as follows:

Trawler	Round weight landed (lb)	kcal per lb	Energy value of landings (kcal)	Energy inputs (kcal)	Efficiency outputs/inputs (percent)
Washington	990,831	171	169×10^6	$1,029 \times 10^6$	16
Japanese	5,378,186	231	$1,242 \times 10^6$	$30,043 \times 10^6$	4

Thus, the Washington fleet is several times more efficient than the Japanese fleet in these terms. The primary reason is the comparative fuel consumption. A Japanese trawler lands about five times as many pounds of fish per year as a Washington trawler, but its fuel consumption may be over 30 times as high.

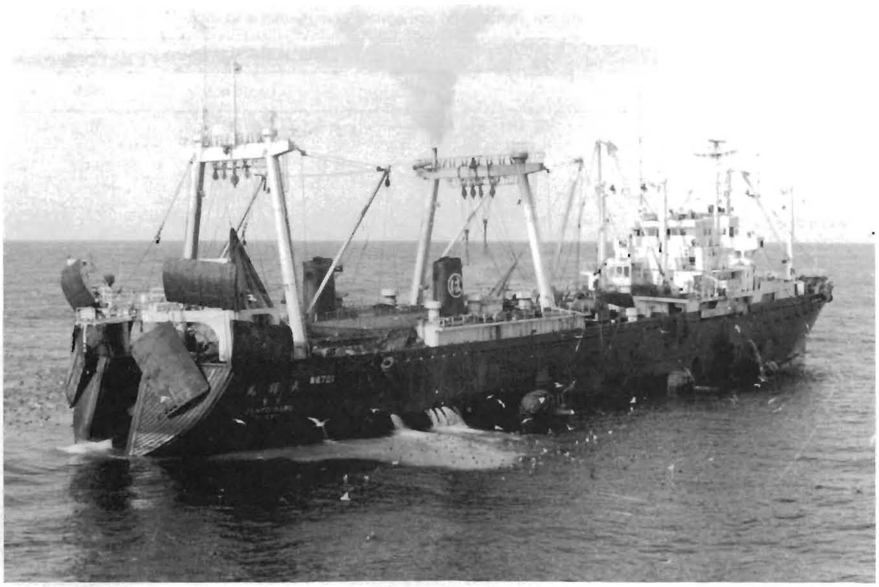
Put into these simpler terms for comparison we see:

	Pounds of fish landed/gal of fuel
Washington trawl fleet	36.55 lb/gal
Japanese trawl fleet	6.65 lb/gal

Other measures of efficiency can, of course, be calculated from the data presented such as pounds of fish per man day, or pounds of fish per gross ton of vessel. For such comparisons, a Washington trawler again appears much more efficient.

DISCUSSION

On an output:input basis the Washington fleet of small, short-trip vessels appears to be more efficient than the Japanese mothership-based fleet of large stern trawlers. The greater amount of fuel per unit of fish caught is the primary reason for the difference. Our figures for fuel consumed by the Washington fleet, we feel, are quite accurate, being based upon annual consumption of 11 vessels. Estimated fuel



Japanese stern trawler.

consumption for the Japanese vessels is less likely to be accurate since we did not have vessel by vessel consumption reports. However, even if we have overestimated Japanese fuel consumption by a factor of two or even three, our basic conclusion that the Washington fleet is more efficient is still valid. It should be pointed out that the Japanese do process some of their catch at sea, which is another energy factor that should be considered. For the scope of this study though, processing energy is not evaluated for comparison.

What are the implications of the foregoing analysis? At the present time the costs of fuel and manpower in the two countries relative to the prices obtainable for fish products must be such that each type of operation is profitable in its respective nation, since both countries operate under a capitalistic system where monetary outputs must exceed monetary inputs in order for industries to survive. Thus, cost efficiency as yet guides the kind of fishery and other enterprises that are carried forth, not energy efficiency. However, if conventional fuels become increasingly costly relative to other resources on world markets and if costs of manpower and resources tend to equalize amongst nations, free enterprise constraints may themselves tend to favor the local, small boat, more energy efficient, fishery operations over the distant water fleets of larger trawlers. Thus, even without some future scheme of global allocation of fuels to their most efficient use, one implication of the foregoing analysis is that distant-water trawl fleets may very well be dinosaurs.

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