Energy Analysis Of Fishing And Processing Fish In Japan

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Introduction

The background to the energy problem is that we are living at the epoch of the use of fossil fuel in the history of man on the earth. Most human activities in the industrialized societies depend heavily on the consumption of fossil energy resourses. Even in agriculture, which is the sector of industry where solar energy is converted into food, increased productivity has been supported through a large amount of fossil energy input. In order to deal with energy management and energy policy, comprehensive understanding on energy use in the individual industry is needed.

When you go fishing, for example, you use not only fuel oil but also non-energy commodities such as fishing boat, pole and line, bait, fishing jacket, ice, ice box,etc. The consumption of energy commodities such as fuel oil and electricity is counted as direct energy input. On the other hand, consumption of non-energy commodities is counted as indirect energy input, because energy is used for the manufacture of non-energy commodities.

There are two methods for estimating the direct and indirect energy requirements of goods and services. One is 'Process Analysis' and the other is 'Input-Output Analysis'. The procedure of Process Analysis is:

- Examine the manufacturing process of the target product and estimate all the energy and non-energy inputs (amount of commodities) required for its production.
- The energy input at the final stage of manufacturing is tallied as the Direct Energy Input.
- Each of major non-energy inputs is examined in the same manner with their energy inputs being tallied as Indirect Energy Input.
- This process is repeated several times, tracing back down each subsequent stage of the goods and services pyramid.
- The process produces a series of gradually terminating energy contributions and is terminated at a point where the indirect figures become negligible.

'Process Analysis' is useful for a detailed study of specific goods or services. However, it is complicated and rather tedious, and sometimes impossible to proceed. On the other hand, 'Input-Output Analysis' is a good tool for macroscopic energy study as long as the Input-Output Table and related information are avallable.

'Input-Output Analysis' is a modeling technique initiated by Leontief (1941) who applied this to a dynamic analysis of economy. 'Input-Output Analysis' is performed on the Input-Output Table, a database in which all nationwide industrial activities are classified into several hundreds of sectors and the monetary flow among these sectors is stored. The monetary flow between the sectors may be converted into energy flow, and may offer information such as what amount of energy is supplied through non-energy commodities to a target product.

An Input-Output energy analysis of agriculture, fisheries, forestry and food processing in Japan has been performed by Tanaka and Udagawa (1981). The result is shown in Fig. 1. The column on the left shows the amount of production in price. The column at the center shows the energy requirement for these production. The column on the right shows the percent of energy input direct as well as indirect (current and fixed).

A glance at Fig. 1 gives us three remarkable points:

1) Food processing sectors take up a prominent share both in production and energy consumption.
2) Fisheries (fishing and aquaculture) take up 18% of agriculture (crop+livestock) in production, but 50% in energy consumption. This means fisheries is an energy intensive sector.
3) Fisheries is a sector whose direct energy consumption (77%) prevails over indirect energy consumption.

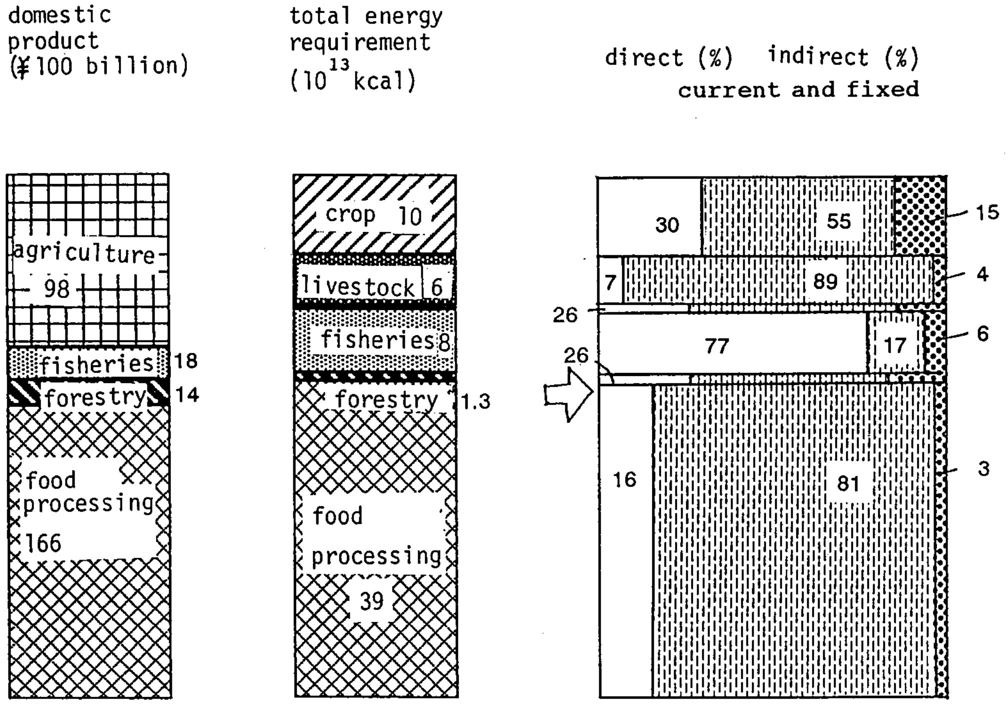
Fig. 2 shows the energy intensity index (in price unit) of selected sectors in Japan. Fig. 2 tells us that fisheries belongs to an energy intensive group of sectors. With all these results based on 'Input-Output Analysis', we have the question:

Why fisheries is energy intensive?

What part of seafood manufacturing process is energy intensive?

Unfortunately, however, 'Input-Output Analysis' is not able to answer these questions, because the Input-Output Table is not yet adequately developed for a detailed study of fisheries.

In this paper we therefore use a Hybrid Method. In the first step of our hybrid method, we examine the manufacturing process of Target Product and estimate the amount of energy input and non-energy commodity input required for its



Source: Tanaba & Udagawa, 1981.

Fig. 1. Energy analysis of agriculture, fisheries, forestry and food processing in Japan, 1975.

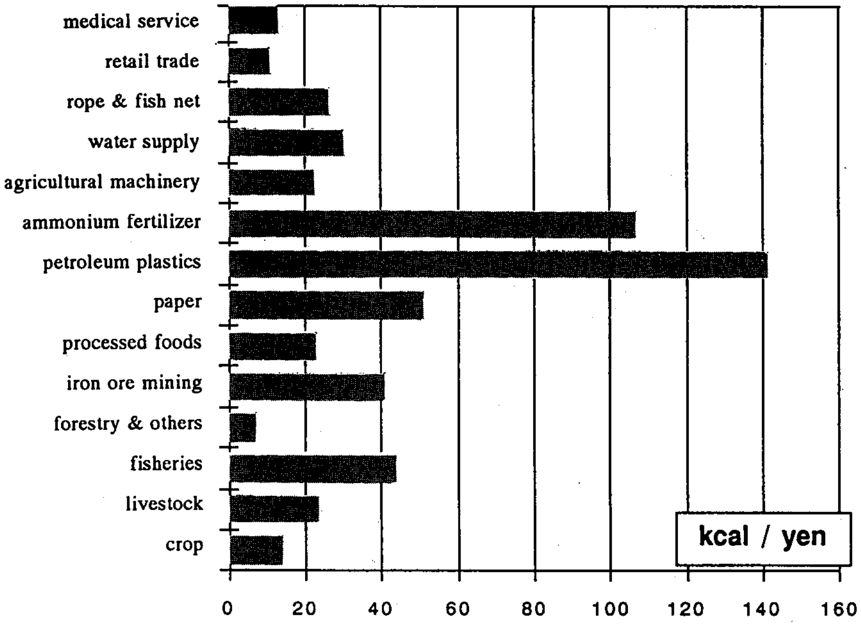


Fig. 2. Energy intensity index of Japanese industries in 1975.

production. In the second step, we estimate the amount of energy, with an aid of 'Input-Output Analysis', which may be used to manufacture the non-energy commodities counted in the first step.

Energy Analysis Of Fishing

Materials And Methods

We used the census data in 1980 published by the Japanese government: Economy of Fishery Establishments(EFE) and Fishery and Aquaculture Production (FAP). In EFE, annual fisheries expenditure per fishery management unit is available in detail as well as basic information concerning fisheries activities such as kind of fishery type, the tonnage of main boat, amount of catch, and the number of fishing days. The expenditure of energy and non-energy goods in price were converted into direct and indirect energy input, respectively. The detailed procedure for conversion is given in Watanabe and Okubo (1989). The sum of direct and indirect energy input per fishery management unit per fishing day was plotted against the tonnage of main fishing boat (Fig. 3). The energy input per fishing day was arranged in a single line for each fishery type. These lines, energy input per day charts (EPD chart) were used later to estimate ${}_tE_j$, the energy input per fishery management unit per fishing day for i-th type fishery operated on t-th level tonnage boat (kcal FMU^{-1} day^{-1}).

In order to estimate the total amount of energy use for the entire fisheries in Japan, we used data recorded in FAP. In FAP, the amount of fisheries production is sorted by the tonnage of boats and by fishery type. The tonnage of boats were sorted into eleven levels: 0-3, 3-5, 5-10, 10-20, 20-30, 30-50, 50-100, 100-200, 200-500, 500-1000, and larger than 1000 GT. Fishery types were separated into thirty nine kinds: trawls (8 kinds), purse seines (6), lift nets (2), gill nets (2), seine nets (3), set nets (3), anglings (6), long-lines (4), and others (5).

The sum of energy input for each i-th type fishery management unit, Q_i, is given by

$$Q_i = \sum_{t=1}^{11} {}_tE_i\,{}_tp_i \qquad \text{— Eq. (1)}$$

where ${}_tp_i$ is the total fishing days multiplied by the number of the fishery management units (FMU) which operate the t-th level tonnage boat (day FMU). For each fishery type, ${}_tp_i$ is available in FAP, and ${}_tE_i$ was given by use of the corresponding EPD chart.

The overall average of energy input per catch (weight of round fish basis) for i-th fishery type, I_i (kcal/kg), is given by

$$I_i = \frac{Q_i}{F_i} \qquad \text{— Eq. (2)}$$

where F_i refers to the total catch by i-th fishery type. F_i is also available in FAP. In general, any one particular species of fish is captured by fisheries of two or more kinds of types. A coefficient referring to the catch of j-th species captured by i-th type fishery, g_{ij}, defined by

$$g_{ij} = \frac{f_{ij}}{F_j} \qquad \text{— Eq. (3)}$$

was calculated using the data recorded in FAP; where f_{ij} is the catch of j-th species by i-th type fishery and F_j is the total catch of j-th species. The overall average of energy input per catch for j-th species, I_j, is given by

$$I_j = \sum_{t=1}^{39} I_i\, g_{ij} \qquad \text{— Eq. (4)}$$

Direct And Indirect Energy Input

Direct and indirect energy input in 1980 per fishery management unit estimated for selected fishery types is shown in Table 1. Fuel oil input was the dominant energy input in most cases, occupying more than eighty percent. This result agrees

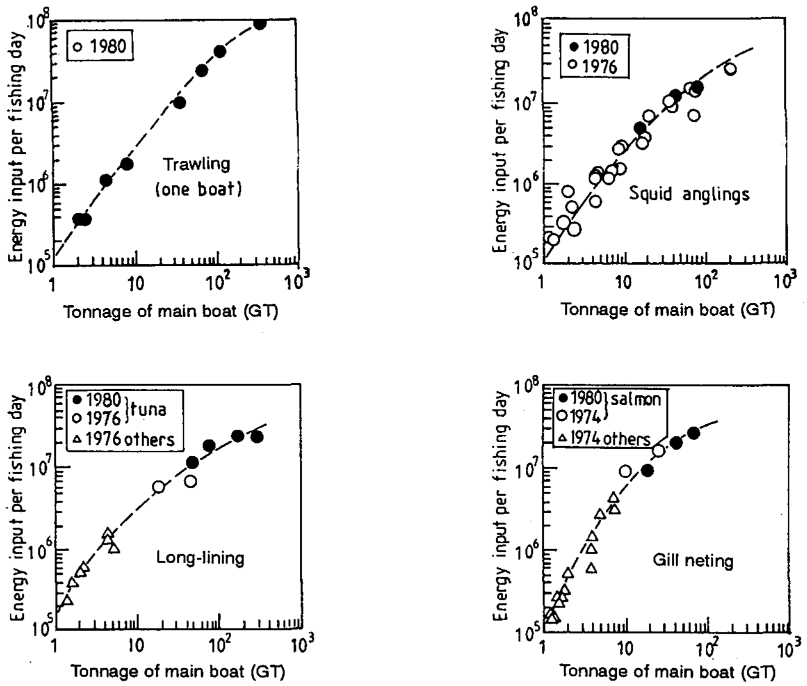


Fig. 3. The energy input per fishing day for selected fishery types. Energy input per fishery management unit per fishing day (kcal.FMU$^{1.d^{-1}}$) is plotted in the ordinate.

Table 1. The estimated annual energy input per fishery management unit for selected types of fisheries.

Item \ Type of fishery	Large trawl in North Pacific	Squid angling	Tuna long-line	Salmon drift gill net
Activity data				
Tonnage of main boat (GT)	362	46.8	294	19.7
Number of fishing days (d)	293	128	364	56
Amount of catch (10^4 kg)	261	13.0	26.9	7.41
Energy input (10^9 kcal)				
Fuel oil	20.2	1.63	9.92	0.399
Boat building & repair	0.503	0.041	0.22	0.028
Fishing gear manuf. & repr.	0.935	0.049	0.24	0.073
Bait	0	0	0.99	0
Ice	0.019	0.00	0.00	0.003
Casing	0.119	0.03	0	0
Miscellaneous goods	0.132	0.02	0.00	0.010
Building & facility	0.027	0.00	0.00	0.004
Total	21.9	1.77	11.4	0.516
Ratio of direct-energy input to total input (-)	0.92	0.92	0.87	0.77
Total energy input per FMU per fishing day (10^6 kcal·FMU^{-1}·d^{-1})	74.9	13.8	31.4	9.21
Total energy input per catch (10^4 kcal·kg^{-1})	0.84	1.36	4.24	0.70

favorably with the estimation by Tanaka and Udagawa (1981), as well as by Leach (1976). Most of indirect energy input was due to the manufacture as well as the repair of fishing boat and fishing gear.

Total Energy Input And Energy Input Per Catch For Each Type Of Fishery

The estimated values of the total energy input, Q_i ,as well as energy input per catch, I_i, for each fishery type is listed in Table 2. The grand total energy input for marine fisheries in 1980 was estimated to be 6.00 x 10^{13} kcal, the break down of which is 28% trawling, 19% angling, 18% long-lining, 10% purse sein and 10% gill net.

The overall average of energy input per catch (round fish basis) for entire marine fisheries was 0.61 x 10^4 kcal/kg, which is similar to or less than that in foreign waters. Hirst (1974) reported that 1.0 x 10^4 kcal of fossil energy input per kilogram catch were required in the entire fisheries industry of the United States of America. Leach (1976) reported 0.78 x 10^4 kcal of fuel oil input per kilogram catch (including trash fish) was required in fisheries of the United Kingdom. He also estimated that fuel oil input per catch was 0.86 x 10^4 kcal/kg in Maltese waters.

Tuna long-line in distant waters was the most energy intensive fishery type (3.5 x 10^4 kcal/kg). The energy input per catch of tuna long-line operated in offshore waters was half that in distant waters. The energy input per catch of costal tuna

Table 2. Energy input for marine fisheries of Japan in 1980.

Fishing method	Total energy input Q_i (10^{10} kcal)	Energy input per catch, I_i (10^4 kcal.kg^{-1})
Trawls	1666	
Mother ship	69.5	0.126
Large trawls in N. Pacific Ocean	227	0.340
Large trawls in Southern Ocean	137	0.676
Large trawls in East China Sea	267	1.34
Shrimp trawl	27.7	0.804*1)
Medium trawl on offshore waters		
(one boat operation)	643	0.804
(two boat operation)	64.4	1.07
Small trawl on coastal waters	230	0.672
Purse seines	618	
Large and medium purse seine		
(one boat operation-tuna & skipjack)	105	1.29
-sardine & others)	447	0.18
(two boat operation)	3.3	0.05
Small purse seine (one boat operation)	46.2	0.083
(two boat operation)	17.2	0.067
Lift nets	130	
Saury stick held dip net	89.4	0.496
Others	40.6	0.227
Gill nets	627	
Salmon drift gill net	40.0	1.54*2)
Others	587	1.54
Seine nets	169	
Beach seine	0.4	0.052
"Patch" seine	52.8	0.421
Boat seine	116	0.702
Set nets	214	
Salmon large set net	40.4*3)	0.678*3)
Other large set net	73.8*3)	0.299*3)
Small set net	99.5*3)	0.638*3)
Anglings	1138	
Skipjack pole-and-line in distant waters	240	1.16
Skipjack pole-and-line in offshore waters	165	1.15
Skipjack pole-and-line in coastal waters	35.0	1.48
Mackerel angling	2.66	0.386
Squid angling	694	1.54
Others	0.89	0.386
Long-lines	1092	
Tuna long-line in distant waters	735	3.47
Tuna long-line in offshore waters	183	1.72
Tuna long-line in coastal waters	28.9	1.25
Others	145	1.39
Others	349	
N. Pacific Ocean tanner crab fishery	16.4	2.08
N. Pacific Ocean long-line and gill net	18.3	0.391
Shellfish collecting	32.8	0.187
Seaweed collecting	33.5	0.187
Others	248	0.752
Total/average	6002	0.609

*1 Assumed same as that of medium trawls.

*2 Assumed same as that of other gill nets.

*3 Estimated from K. Matsuda: in Energy Saving in Fisheries (ed. H. Watanabe). Tokyo University of Fisheries, 1985, pp. 7-22.

Table 3. **Energy input per catch for each species.**

Common name		Scientific name	Energy input per catch $\left(\frac{10^4 \text{ kcal}}{\text{kg-round fish}}\right)$
English	(Japanese)		
Tunas average			2.41
Bluefin tunas	(Maguro)	*Thunnus thynnus & T. mackoyi*	2.93
Albacore	(Binnaga)	*Thunnus alalunga*	1.51
Big eye tuna	(Mebachi)	*Thunnus obesus*	3.07
Yellowfin tuna	(Kihada)	*Thunnus albacares*	2.20
Young tunas	(Meji)	*Thunnus* spp.	1.05
Marlins average			2.55
Striped marlin	(Makajiki)	*Tetrapturus audax*	2.54
Swordfish	(Mekajiki)	*Xiphias gladius*	2.46
Black marlins	(Kurokawa)	*Makaira* spp.	2.71
Sailfish	(Bashokajiki)	*Istiophorus platypterus*	1.97
Bonitos average			1.25
Skipjack	(Katsuo)	*Euthynnus pelamis*	1.28
Frigate/bullet mackerel	(Sodagatsuo)	*Auxis* spp.	0.71
Sharks	(Same)	*Elasmobranchii*[*1)]	1.88
Salmons	(Sake)	*Oncorhynchus* spp.	1.13
Pacific herring	(Nishin)	*Clupea pallasi*	0.86
Sardine average			0.20
Sardine	(Maiwashi)	*Sardinops melanostictus*	0.18
Round herring	(Urumeiwashi)	*Etrumeus teres*	0.14
Japanese anchovy	(Katakuchiiwashi)	*Engraulis japonica*	0.27
Whitebait	(Shirasu)	*Engraulis japonica*[*2)]	0.58
Horse mackerels average			0.19
Japanese horse mackerel	(Maaji)	*Trachurus japonicus*	0.22
Mackerel scads	(Muroaji)	*Decapterus* spp.	0.18
Mackerels	(Saba)	*Scomber* spp.	0.22
Pacific saury	(Samma)	*Cololabis saira*	0.51
Yellowtails	(Buri)	*Seriola* spp.	
excluding cultured fish			0.48
including cultured fish			2.82
Flounders average			0.66
Olive flounders	(Hirame)	*Paralichthys olivaceus*	0.97
Righteye flounders	(Karei)	*Pleuronectiformes*[*3)]	0.65
Codfishes average			0.52
Pacific cod	(Madara)	*Gadus macrocephalus*	0.62
Alaska pollack	(Suketodara)	*Theragra chalacogramma*	0.52
Arabesque greenling	(Hokke)	*Pleurogrammus azonus*	0.80
Ocean perches	(Menuke)	*Sebasters* spp.	0.47
Thornyhead	(Kichiji)	*Sebastolobus marcochir*	0.82
Argentines	(Nigisu)	*Argentina & glossanodon* spp.	0.80
Croakers	(Nibe, Guchi)	*Sciaenidae* spp.	1.26
Lizard fishes	(Eso)	*Synodotidae* spp.	1.04
Medusafishes	(Ibodai)	*Centrolophidae* spp.	1.30
Pike eels	(Hamo)	*Muraenexox* spp.	1.28
Cutlassfish	(Tachiuo)	*Trichiurus lepturus*	0.89
Searobins	(Hobo)	*Triglidae* spp.	1.36
Rays	(Fi)	*Rajiformes*	1.36
Spotted mackerels	(Sawara)	*Scomberomorus* spp.	1.00
Dolphins	(Shiira)	*Coryphaena* spp.	0.93
Sea breams average		*Sparidae* spp.	0.92
including cultured fish			1.09

[*1] Excluding *Rajiformes*.
[*2] Including *Sardinops* spp. and others.
[*3] Excluding *P. olivaceus*.

Table 3. Energy input per catch for each species (*contd.*).

Common name		Scientific name	Energy input per catch $\left(\frac{10^4 \text{ kcal}}{\text{kg-round fish}}\right)$
English	(Japanese)		
Flyingfishes	(Tobiuo)	*Exocoetidae* spp.	0.99
Mullets	(Bora)	*Mugilidae* spp.	0.98
Japanese seabass	(Suzuki)	*Lateolabrax japonicus*	0.87
Sand lances	(Ikanago)	*Ammodytes* spp.	0.54
Sailfin sandfish	(Hatahata)	*Arctoscopus japonicus*	0.80
Shrimps/prawns/lobsters average			1.36
Spiny lobster	(Iseebi)	*Panulirus japonicus*	1.43
Tiger shrimp	(Kurumaebi)	*Penaeus japonicus*	0.83
Crabs average			0.79
King crab	(Tarabagani)	*Paralithodes camtschaticus*	1.07
Tanner crabs	(Zuwaigani)	*Chionoecetes* spp.	1.12
Swimming crabs	(Gazami)	*Portunus* spp.	0.98
Squids/cuttlefishes average			1.36
Squids	(Surumeika)	*Todarodinae* spp.	1.48
Cuttlefishes	(Kouika)	*Sepiidae* spp.	0.79
Shellfish average			0.41
Abalones	(Awabi)	*Haliotis* spp.	0.27
Horned turban	(Sazae)	*Turbo cornutus*	0.51
Hard clams	(Hamaguri)	*Meretrix* spp.	0.29
Littleneck clams	(Asari)	*Ruditapes* spp.	0.21
Yesso scallop	(Hotategai)	*Patinopecten yessoensis*	0.65
Giant Pacific oyster	(Kaki)	*Crassostrea gigas*	0.41
Sea weeds average			0.19

long-line was 30% smaller than that of offshore tuna long-line. As far as tuna long-line is concerned, the further the operation was located from the Japanese coast, the more energy-intensive it was. As for skipjack pole-and-line, on the other hand, the difference of waters on operation seemingly did not affect energy input per catch.

Small purse seine and beach seine required the minimum amount of energy per catch. The large and medium purse seine were energy intensive when they were for catching tuna or skipjack, but not energy intensive for catching sardine.

Energy Input For Catching Each Species Of Fish

The overall average of energy input per catch for j-th species, Ij, estimated by Eq.(4) is shown in Table 3. The most energy intensive species were marlins and tunas, which are four times larger than the overall average. On the other hand, sardines, horse mackerels, and mackerels were species which required relatively little energy.

Rawitscher and Mayer (1977) estimated the energy used for harvesting selected fish species in US waters; input energy per catch (round fish) was 0.46×10^4 - 2.0×10^4 kcal/kg for salmon, 0.43×10^4 - 0.81×10^4 kcal/kg for codfish, 0.53×10^4 kcal/kg for flounder, 1.6×10^4 kcal/kg for tuna, and 7.4×10^4 kcal/kg for shrimps. These values are similar to those in Japanese waters (Table 3). Concerning sardine or anchovy, however, energy input in Japanese waters (1800 kcal/kg) is significantly large; three times larger than that in US waters(580 kcal/kg) and 14 times larger than that in Peruvian waters (129 kcal/kg). The difference in these three could be partly due to the difference in scale of fishery engaged in fishing sardine or anchovy. In Japan sardine is capture mainly by large and medium purse seine with one boat operation, which requires two or three times more energy than that of small purse seines. In other words, the energy

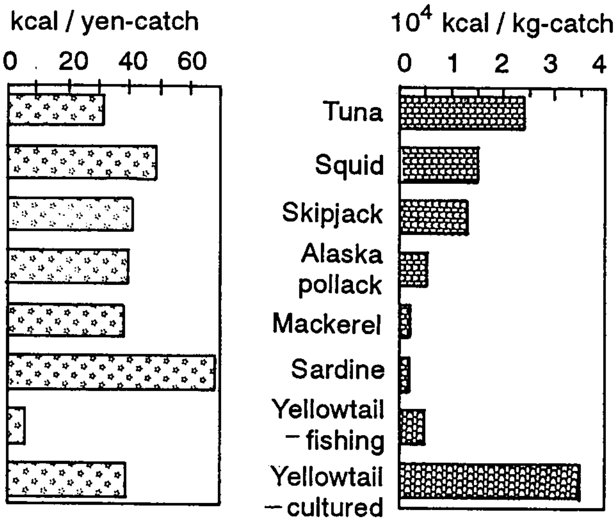


Fig. 4. Energy input per catch for selected species on the basis of price (Japanese yen) of catch as well as of kilogram of catch.

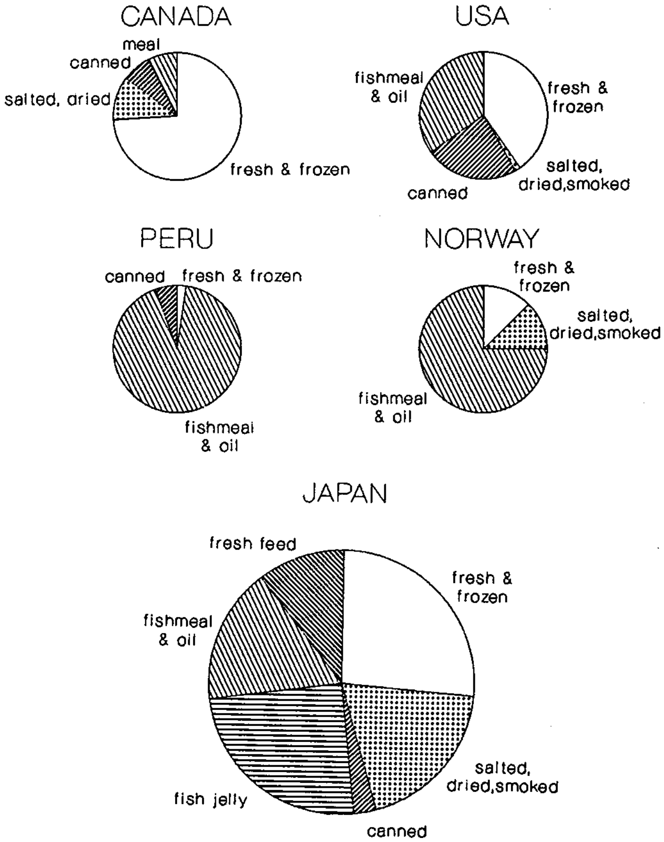


Fig. 5. How they used fish (1976).

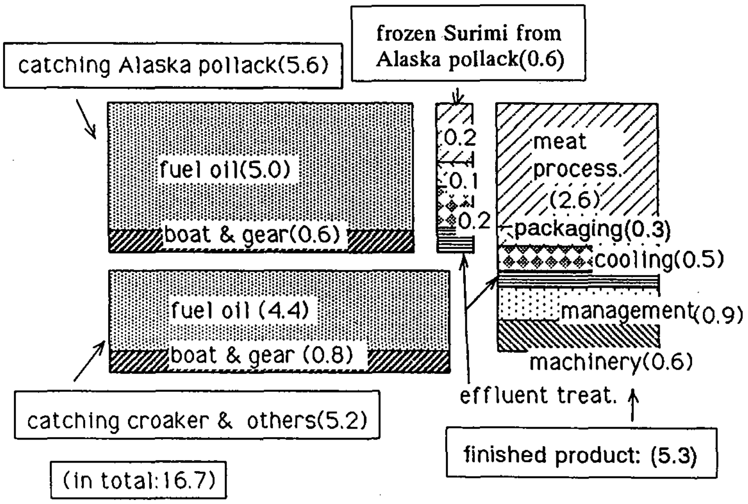


Fig. 6. Total energy input for fish jelly products in Japan (10^3 kcal/kg finished product), 1974.

input per catch of sardine in Japan captured by small purse seine is comparable to that in US waters. However,the difference in energy input between the small pure seine in Japanese waters and anchovy fishery in Peruvian waters is still large. The cause of this difference could be the difference in the use of non-powered vessels as well as the richness of fishing grounds in Peruvian waters.

Energy input per weight of fish for yellowtail culture was 3.6×10^4 kcal/kg, which is seven times larger than that for yellowtail by marine fishery (0.5×10^4 kcal/kg). The cause of large energy input for yellowtail culture is that yellowtail is fed with a lot of sardine, ie, 7.8 kg of sardine is consumed for one kg growth of yellowtail.

Energy input per catch for selected species are shown in Fig. 4 on the basis of price (Japanese yen) of catch as well as kilogram catch. This figure tells us that energy input per catch in price for most species level to the value of around 40 kcal/yen, although the value on kilogram basis differ greatly from one to another. This suggests that the fuel oil input per catch in price had worked as a guide line in the management of fishing. Sardine and yellowtail are exceptions in the capture fisheries. The low price of sardine is the cause for its large value of energy input per yen-catch. This low price is supported by its extraordinarily big catch today. The low value of energy input per catch for yellowtail was consequent to its high price as well as that it was captured mainly by an energy-saving method such as set nets or purse seines.

Energy Analysis Of Processing Fish

The Japanese have a variety of ways in utilizing fish (Fig. 5). Twenty percent of the total catch was processed into salted, dried or smoked products, 2% was canned, 25% went into jelly products, 17% went to fish meal and fish oil, 10% was used as fresh feed for fish culture, 27% was marketed as fresh fish at the fishmonger's. Energy requirement for each of these fish processing industries were estimated.

The result of energy analysis on fish jelly products is shown in Fig. 6 . We can see that fishing occupies a fairly large percentage of energy input; the percentage has become much larger these days. It also shows that the surimi manufacturing industry seems to be very successful in the efficient use of energy.

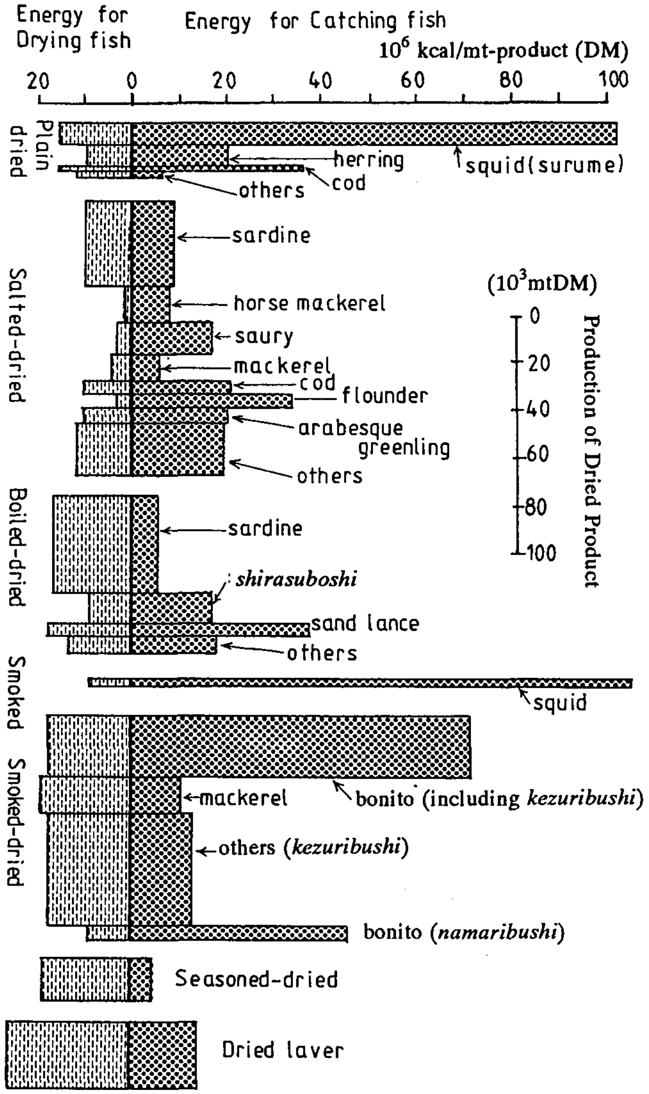


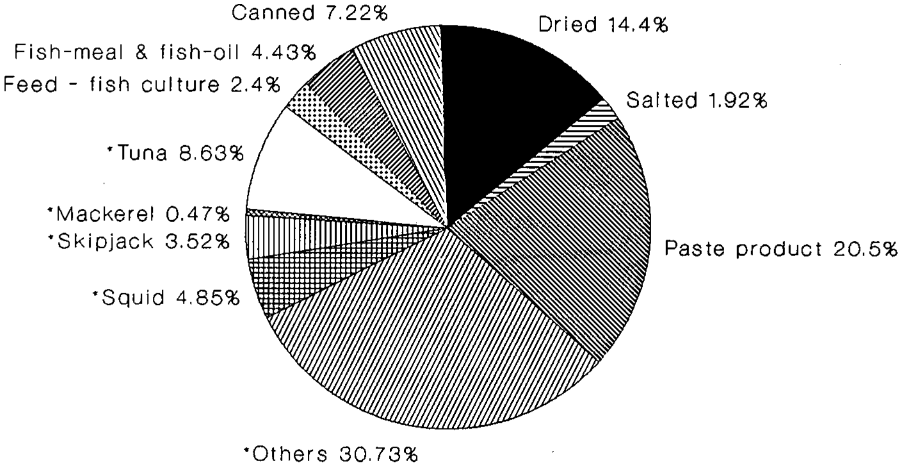
Fig. 7. The total energy requirement for individual item of dried marine products manufactured in 1980 in Japan.
The horizontal axis refers to the energy input (million kcal) per mt of product (dry matter, DM). The length of the bar stretching out from the base line to the right-hand side represents the energy for catching. The length of the bar stretching out to the left represents the energy for drying fish. The vertical axis refers to the production of dried products on dry matter basis. The area of each individual bar therefore refers to the energy required.

The energy requirement of dried marine products is shown in Fig. 7. The figure tells us that energy requirement for drying fish, which is within the range of 20 x 10^6 kcal/mt-DM*-product, is comparable to that for catching fish except bonitos and squids. Catching bonitos and squids are energy intensive (50 x 10^6 - 70 x 10^6 kcal/mt-DM-product). Since the dried products made of bonito and squid are very popular in the Japanese market, the large amount of energy used for the manufacture of these products could have been carried out because of their high prices.

The grand total of energy requirement for fishing and fish processing industry in Japan was 94 x 10^{12} kcal in 1980. Its breakdown is shown in Fig. 8.

Conclusion

The conclusion to be drawn is as follows: the process of catching fish is energy intensive, while fish processing is not. The amount of energy spent on catching a unit of fish depends on the type of fishing operation.



* Fresh (not processed) & frozen

Fig. 8. Total energy input in fisheries & related industry in Japan, 94 x 10^{12} kcal (1980).

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* DM = Dry matter

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Discussion

In the discussion, Dr Watanabe informed the meeting that an attempt had been made to include labour energy in the calculation of energy consumption. However, the idea of including human energy and food as energy had not proved to be acceptable and, so far, this controversy has not been resolved.

As regards the basis of energy calculation, Dr. Watanabe explained that the discussion was based on the total fossil energy input which was the sum of direct and indirect energy; for example, one kilowatt-hour of electricity was equivalent to 860 kcal in terms of net energy conversion. In this study, however, one kilowatt-hour of electricity was converted to 2000 kcal, considering the efficiency of the power station and the energy cost for building power station.

Asked whether work has been done on energy in waste products or waste treatment, Dr Watanabe replied that some aspects of waste energy known as scrap energy were considered in the study. However, in some parts of the investigation this was not considered. Thus this could be a new area of study in the future.