ENERGY PERSPECTIVES
ON THE MUSSEL FISHERY OF THE
EASTERN SCHELDT ESTUARY

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ABSTRACT

An energy systems analysis was made of the mussel fishery in the Eastern Scheldt, a recently dammed estuary in Holland. Various kinds of inputs were evaluated in common units of Solar Emergy (solar embodied energy). Initially work of natural ecosystems in the Wadden Sea generates juvenile mussels. As these are transplanted for further growth in the Eastern Scheldt, harvested, successively handled, processed and distributed to retail consumers, a high proportion of energy from environmental work is maintained matching that purchased from the economy. The ratio of economic inputs to environmental inputs in emergy units ranges 0.7 to 5.6, comparable with the general ratio of 3.5 for the Netherlands economy and, thus, economically competitive.

Transformity, a measure of the total energy embodied in the mussels, increased from 0.8 E6 SEJ/J for initially harvested mussels to 7.3 E6 SEJ/J for the final retail products, values in the same range as other protein-rich food products such as mutton, calves, and shrimp.

Net energy yield ratios range 1.2 to 5.1, indicating a general net contribution to the economy. At auction the macroeconomic value, estimated from emergy contribution, was 2.5 times the sale price. As used by retail consumers, the total contribution was 169 million dollars (1978 $) of which 19% was a free contribution from the environment.

The energy characteristics of the mussel fishery indicate the industry to be competitive and appropriate for use of an environmental product in a developed economy.

INTRODUCTION

Questions of Energy Use in Fisheries

Fishery products are generated by the world ecological systems followed by successive work of fishermen, processes, transporters, wholesalers, etc. At each stage in processing fishery products more work by humans and machines is added. More cost is added at each stage also. The dollars added measure the additional services. To adequately understand the relative importance of the different inputs to the fishery, all can be represented in a common measure, the embodied equivalent solar energy (solar emergy). What are the proportions of work contributed by environment, by machinery, by human services? What ratio of human inputs to environmental inputs is observed to be economic? How does the environmental contribution to the economy compare with market prices? In this paper these questions are evaluated for a mussel fishery in the Eastern Schelde of Holland.

The mussel fishery, which is analyzed in the pages that follow, begins with larvae, post-larval attachment, and growth in the Wadden Sea (see Figure 1). Many of the mussels harvested from this sea are placed in the eastern Scheldt where they attain additional growth. Many of these mussels are processed further by placing them in an area with a peat substrate so that sediments in the digestive system are cleared out. Mussels are auctioned, transported, distributed to retail outlets in the Netherlands and also to Belgium and France. The various inputs from the environment and those purchased from the economy were evaluated in energy, emergy, and economic terms.

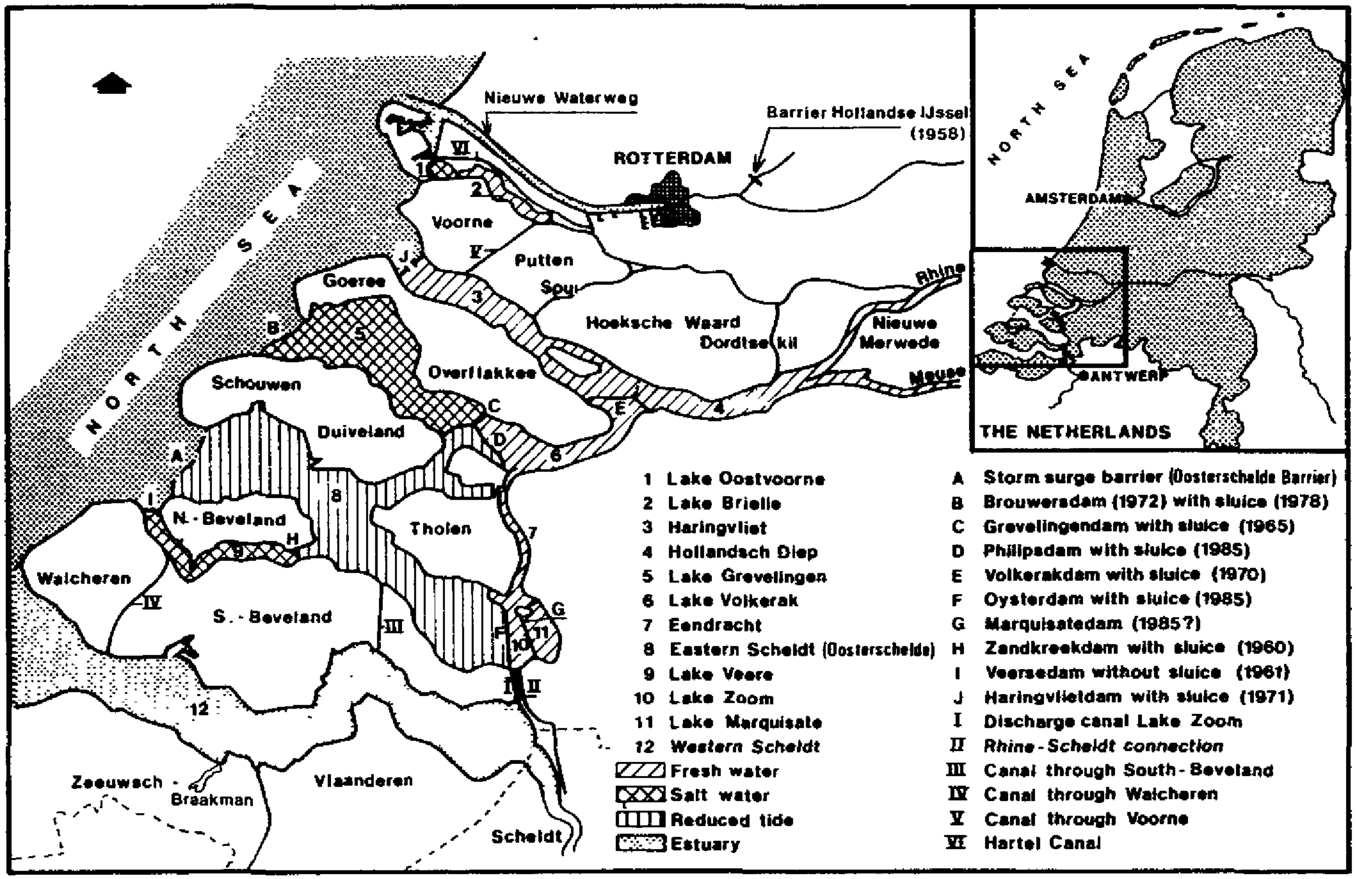

Figure 1. The Delta Region of the Netherlands.

The Eastern Scheldt Ecosystem

The southwestern coastal region of the Netherlands is a braided network of estuaries, islands and peninsulas known as Zeeland or the Delta Region (Figure 1). Historically the topography has shifted according to changes in the erosional and depositional patterns of the three major rivers which enter the North Sea from Zeeland, the rivers Rhine, Maas (Meuse), and Scheldt. The past few centuries, particularly the twentieth, have witnessed the declining influence of these rivers as dikes, dams, locks and canals have established a network of commercial watercourses.

The Eastern Scheldt, ironically enough, is an estuary whose connections with the Scheldt have been cut off since the 19th Century, and contact with the Rhine and Maas Rivers remains very restricted. The Eastern Scheldt, therefore, has relatively minor freshwater influence. This isolation currently appears to be beneficial considering the toxic load of heavy metals and chemicals borne by these rivers which might severely limit or destroy the local shellfish industry.

The major hydrological influence on the Eastern Scheldt is tidal. Proceeding from the mouth of the estuary landward the tidal range varies from 2.8 m to 3.7 m. Each tidal cycle moves approximately 1.25 E9 cubic meters of water into and out of the estuary with a maximum flow velocity of 1 m/s (Knoester et al., 1983a). The horizontal component of tidal flow is about 10-15 km of motion back and forth for each cycle. Tidal functions can be numerous including: 1) nutrient import, 2) waste export, 3) environmental cues for feeding activity and benthic diatom production, 4) erosion and deposition of sediments, 5) loosening and potentially oxygenating sediments, 6) spreading detritus more uniformly around the estuary so it does not concentrate in the gullies where it is more likely to be anaerobic, 6) transport of plankton and various reproductive life stages.

While the strongest influence on water quality clearly seems to be tidal, since chlorinity levels (15.5-17.5 g/1 Cl) are nearly the same as the North Sea, freshwater sources add significant amounts of nutrients to the Eastern Scheldt. The old connection with the Rhine, the Volkerak, releases the following proportions of the nutrient load to the Eastern Scheldt: 1) 55% of total P, 2) 75% of total N, and 3) 55% of total Si (Knoester et al., 1983a). However, nutrient amplification of phytoplankton productivity is limited by relatively lower light intensity. Tidally induced turbulence, with some contribution from the characteristically high winds of the Zeeland, suspends enough particulate matter to reduce Secchi depths to 1 to 2 m (Knoester et al., 1983a).

The Eastern Scheldt, Figure 2, extends over some 44,000 ha. A significant portion consists of intertidal flats which comprise a few islands and large sections of the estuarine perimeter. Contiguous with these intertidal flats on the perimeter are salt marshes with freshwater creeks. The potential for productivity is high with highly productive organic exporters such as salt marshes adjacent to mud flats which are rich in nutrients and which daily receive pulses of tidal energy.

The central and western parts of the estuary are predominantly deep tidal channels, particularly on the southern edge where the channels reach 50 m in depth. The tidal channels of the northern edge are less deep, 25 m. The pattern of deeper southern and shallower northern channels and large expanses of tidal flats in the eastern and central sections of the estuary is in keeping with the regional topography. This topography is the result of historical water flow patterns wherein fast, denser, tidal streams would push sediment and detritus along the benthic southern edge and deposit its load

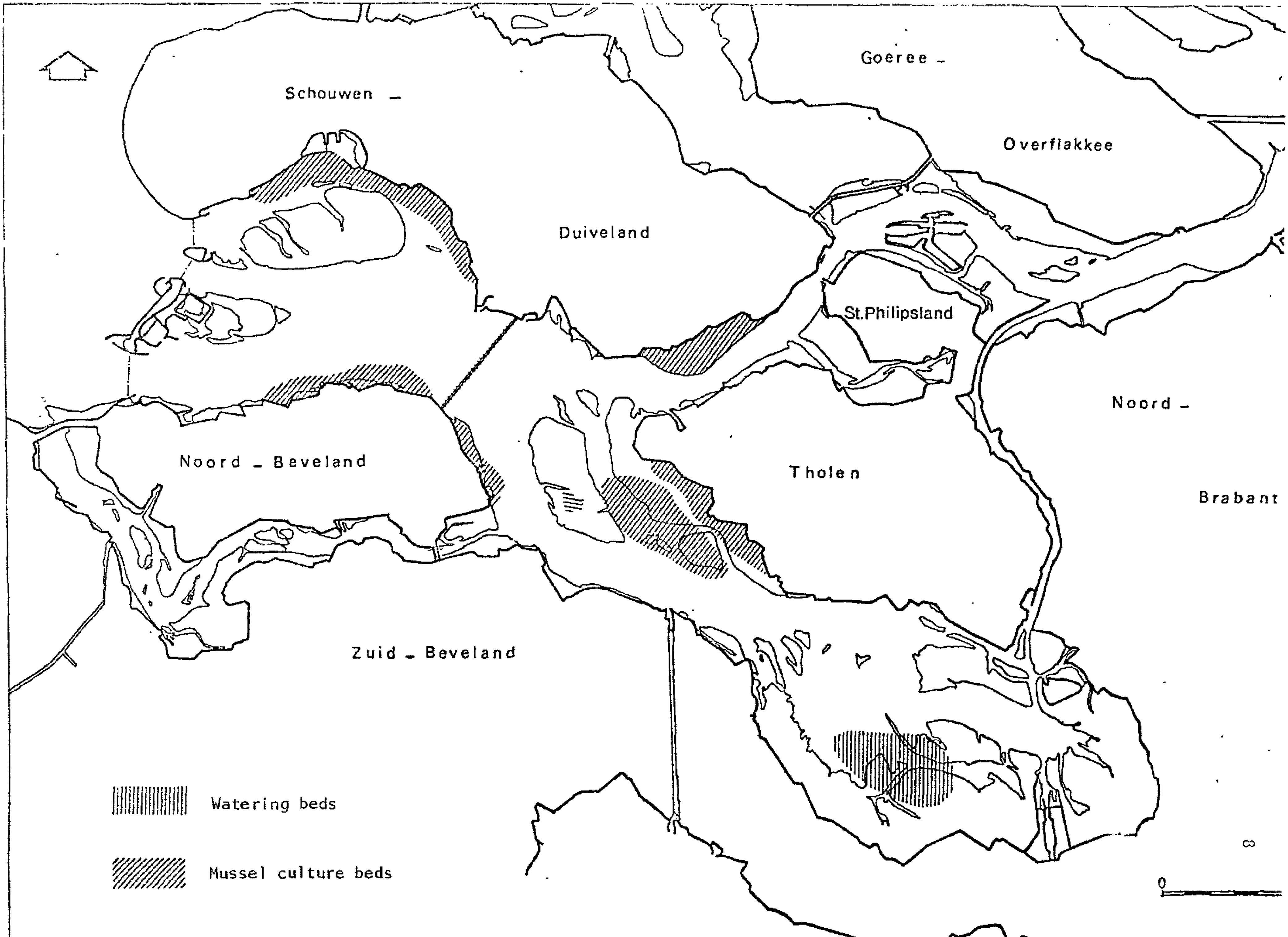

Figure 2. Eastern Scheldt Estuary.

as it was slowed by riverine flows in the eastern part of the estuary. During ebb tide the dominant riverine flows would spread organic matter back toward the central part of the estuary.

Tidal energy subsidy, relatively high nutrient levels and a mild climate create the potential for high productivity and fairly high species diversity. One measure of productivity might be the 30 E6 kg (whole weight) of mussels harvested each year. Over two thousand species can be found in the Eastern Scheldt (Knoester et al., 1983a).

The Eastern Scheldt Mussel Fishery

The Eastern Scheldt contains expansive intertidal mudflats with a large potential for shellfish productivity, but even higher levels of productivity are achieved through human applications of technology and fossil fuel energy. Shellfish productivity can be related to the amount of clear substrate available, and, as diagrammed (Figure 3), some of mussel culture involves raking to clear space for mussels by removing competing macroalgae, barnacles and cockles as well as predatory starfish. Then the mussel culture beds receive the maximum tidal services of import of nutrients, algae and oxygenated water and export of feces and toxic substances.

Fishery effort also involves serial transport and deposition of different life stages of mussels to the habitat most appropriate for their growth. Mussel spats and juveniles from the Wadden Sea (post-pelagic juveniles) are seeded in predominantly intertidal areas near the northern side of the estuary mouth. This frequent exposure to air stimulates shell hardening at the earliest settling stage. After several months to several years these juvenile mussels are removed and transported to a multitude of relatively muddy subtidal flats (mussel growth plots, Figure 4) where flesh weight gain is maximum. It is at this stage that raking and space

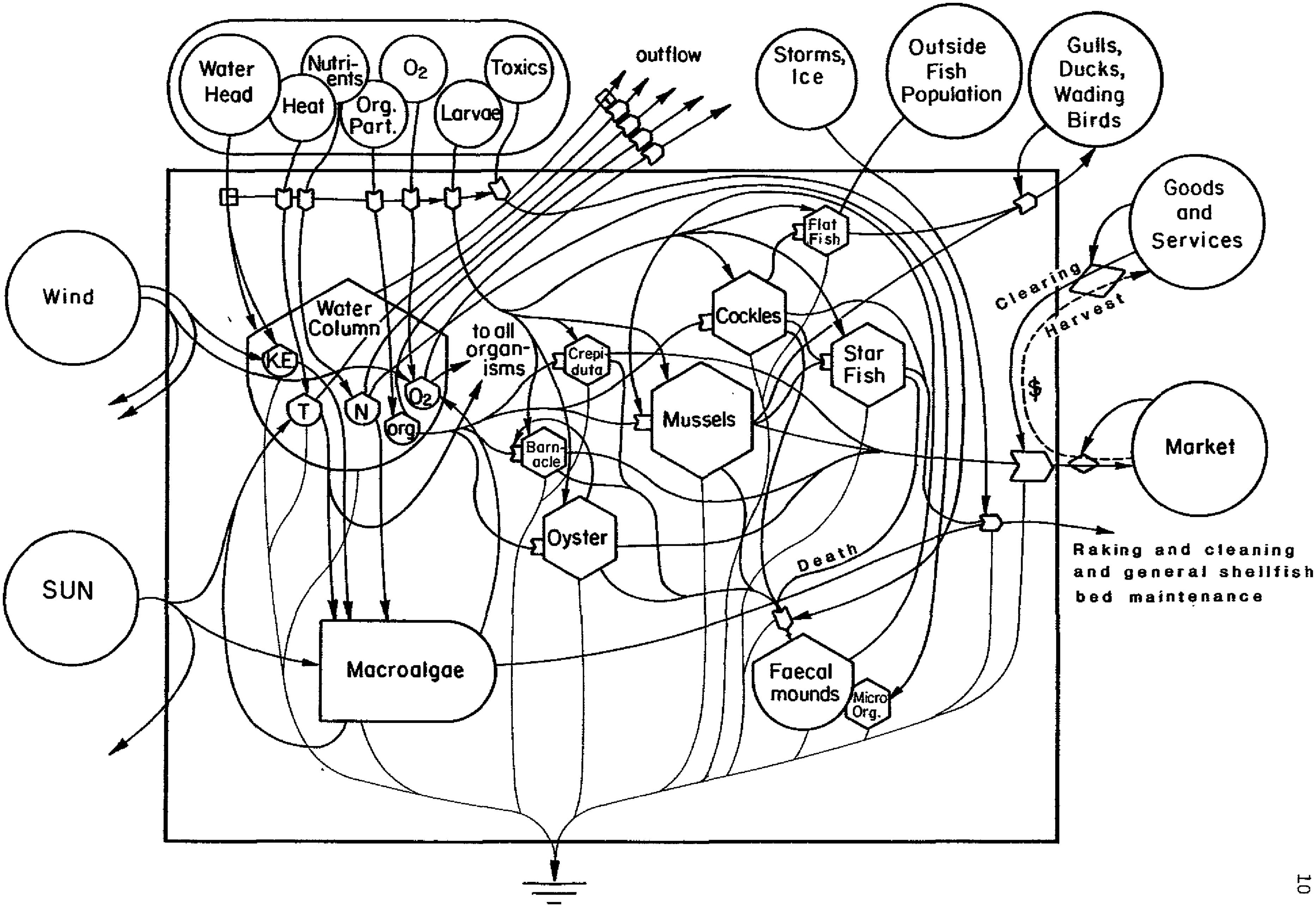

Figure 3. Eastern Scheldt Intertidal Zone.

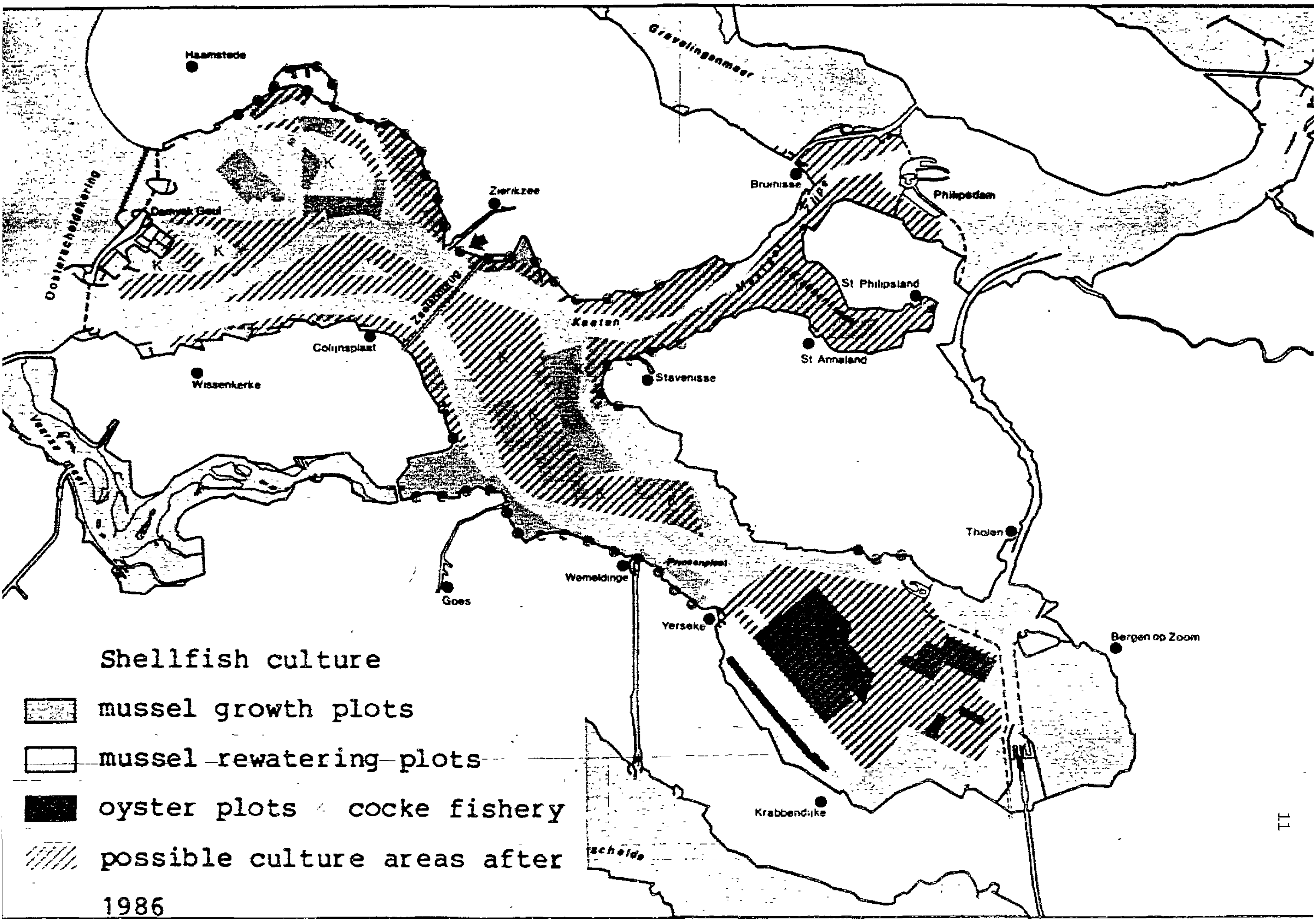

Figure 4. Eastern Scheldt Mussel Fishery Areas.

clearing occur. Between a year and 16 months later these mussels are harvested and auctioned at market. Those mussels which are large enough but not sold or are deemed too small are returned to the same beds and are considered part of a general "Mussel Fund" whose sale a year later benefits the industry in general. Those mussels of marketable weight are taken to the Reimerswaal-Yerseke watering beds (mussel rewatering plots, Figure 4). The peat substrate issues a much lower sediment load to the water column over these watering beds, and the mussels generally clear their stomachs of sediment over the period of a few weeks. The low filtration demands of such quiet water allow mussels to recover from the stress of exposure during auctioning and increases survivability during subsequent transportation. Final harvest is done with heavy tackle to clear the watering beds of accumulated sediment, and the mussels are taken to Yerseke for final processing and transport.

The Delta Barrier Project

A rare combination of wind, tides and currents during a winter storm in February, 1953, raised the water level almost 4.2 m in the Zeeland. As a result nearly 1800 people were drowned. 150,000 ha were flooded with damages of over 1.5 E9 guilders (Stevelink, 1979). Four years deliberation resulted in the Delta Act of 1957 which mandated, among other things: 1) strengthening the dikes, 2) shortening the coastline and closure of the estuaries with a barrier and 3) linking Antwerp and the Rhine with a new shipping route.

Increasing awareness of environmental problems in the 1960's raised questions about the advisability of completely shutting off the Eastern Scheldt estuary (the only one remaining of those projected to be closed in the shortening of the coastline) to tidal influence. This question was particularly acute given the dependence of the mussel fishery on tidal energy subsidies. In 1974 the decision was made to modify the barrier design to allow tidal exchange to occur. Thus, in times when the dikes would not be threatened by storm surge the barrier would remain open, diminishing tidal amplitude by no more than 10-15%. This storm surge barrier should be fully operational by 1986.

The suggestion has been made that barrier closure under non-storm conditions might be an effective emergency tool to counter 1) a catastrophic spill of toxic substances in the North Sea which might kill estuarine biota, 2) any pulse of cold which might destroy the mussel fishery. Such a disaster of the second kind did occur in 1963 when cold continental winds kept the relatively warmer water off the tidal flats and the entire oyster population froze to death. Those people responsible for barrier operation may be involved with decisions comparing the value of dikes and living organisms which support an industry. The question arises as to how such a value system of human and natural systems could be created so as to aid decisions which might have to be made in a matter of hours during storm conditions.

Energy Analysis

Many ecologists who have studied primal systems (systems not overtly controlled by human culture) have repeatedly found it was not enough to understand the activities and exchanges between species, for the dominating influences always seemed to emerge from the next larger system. In more and more cases, given the explosive growth of human society, human culture has been a major part of the larger system encompassing and influencing the primal system. Many studies of systems today involve human and primal subsystems.

At first glance the study of human and primal systems might seem awkward since money is usually seen as the apparent controlling cycle in human systems, and money does not cycle in primal systems. However, one may use a more fundamental measure of physics, the potential driving any system, the work accomplished. As systems organize, the species available from prior evolution are selected that maintain the processes which accomplish the maximum rate of useful work (power). Thus, the dominant processes of any system can be described in terms of their useful energy flow, whether accompanied by money or not.

Energy can be useful as a currency measuring system interactions only if one recognizes energy's range of quality. According to the second law of thermodynamics, in any work process some energy is given off in a degraded form (heat) which no longer has the potential to drive a work process. As energy is passed up a food chain, each work process involves the consumption of one organism by another, and at each step the actual amount of energy available decreases. So the actual amount of energy in a cow is greater than that of the human which consumes it, but the energy quality of the human is greater because it takes many joules of cow to create one human joule.

If every process in a system is described by energy of the same quality or ability to do work, then more reliable comparisons between processes can be made. For example, if every system interaction is described by the amount of solar energy needed to make that interaction possible (the amount of solar energy "embodied" in that process) then this common solar basis ensures that there are no hidden sources of influence or ability to do work when comparing that interaction with others. Embodied solar energy has been called solar emergy (Scienceman, 1984).

Energy, put on the common basis of emergy (equivalent solar units), can be a useful descriptor of the abilities to do work in and between primal and human systems. The flexibility of human choice is included in such analysis, for human society has long experience in discarding wasteful work processes. Certainly the current use of human ingenuity to eliminate shortages in basic resources by increasing recycle processes is very similar to the kind of system selection which has been witnessed in primal systems.

Definitions

The following energy terms are used throughout this paper:

1) Energy Transformation Ratio (ETR): This is the ratio of the equivalent sunlight energy during a period of time to the total actual energies of a particular form (for example, rain, tides, waves). This ratio expresses the amount of solar energy which is required to produce each joule of energy found in any kind of matter, living or non-living, or in any kind of energy flow. Thus, the ETR of wind is 1268 SEJ/J as shown in Odum et al. (1983) Table 3.1. In other words, 1268 solar joules are needed to produce each joule of surface wind energy. An ETR is the reciprocal of the energy "efficiency" of a process and allows comparisons with other processes. The ETR of shrimp harvested in the Gulf of Mexico is 3.77 E6 SEJ/J (Fonyo, 1983). The energy transformation ratio has been called a transformity (Scienceman, 1985).

2) Embodied Energy (Emergy) is the amount of equivalent energy units of one type which were needed to create an object or process and are thus "embodied" in them. Following the example of the energy transformation ratio for wind, 1268 solar joules are embodied in each joule of wind.

3) Energy Quality describes effectiveness and flexibility in use of an energy type. In general, the more energy that is embodied in an object or process the greater its quality needs to be to justify its production and use. For example, electricity is a form of energy of higher quality than wind. Far more solar energy (15.9 E4 solar joules vs. 1268 solar joules) is required to produce one joule of electricity than one joule of wind. This one joule of electrical energy, by acting as an amplifier on other processes, can generate more work than one joule of wind energy. The diversity of forms of work or forms of energy (heat, mechanical or chemical) which electricity can produce far exceeds the capabilities of wind energy.

METHODS

The procedures employed for this paper's analysis are listed below. See also appendix paper (Odum, 1983).

1. An overview diagram was drawn using energy symbols to show features of the system and its external interactions. The symbols used to describe an energy system (see Odum, 1983) form an energy language which gives a diagram several levels of information. These symbols reflect energy constraints, kinetic relationships, macroeconomic flows and causal influences for all the dominant processes in the system.

2. A simplified diagram was drawn by aggregation of the complex one to help define the essential sources, flows, and storages.

3. An energy analysis table was prepared with four columns, (a) energy, (b) energy transformation ratio (transformity), (c) solar emergy, and (d) macroeconomic value. Calculations of these quantities were made for the flows and storages in the diagram.

4. The contributions of environmental work were compared to those by human service and perspectives drawn from several ratios and from summary diagrams.

More detailed information about energy flow calculations and transformation ratios, their derivations and rationales for use in particular examples, is available in manual form (Odum et al., 1981 and Odum et al., 1983).

RESULTS

Overview Diagram

Based on information about land use, regional economy and ecosystem principles, Figure 5 is an overview diagram of the mussel industry including environmental and economic inputs. All the major influences and energy flows recognized were included.

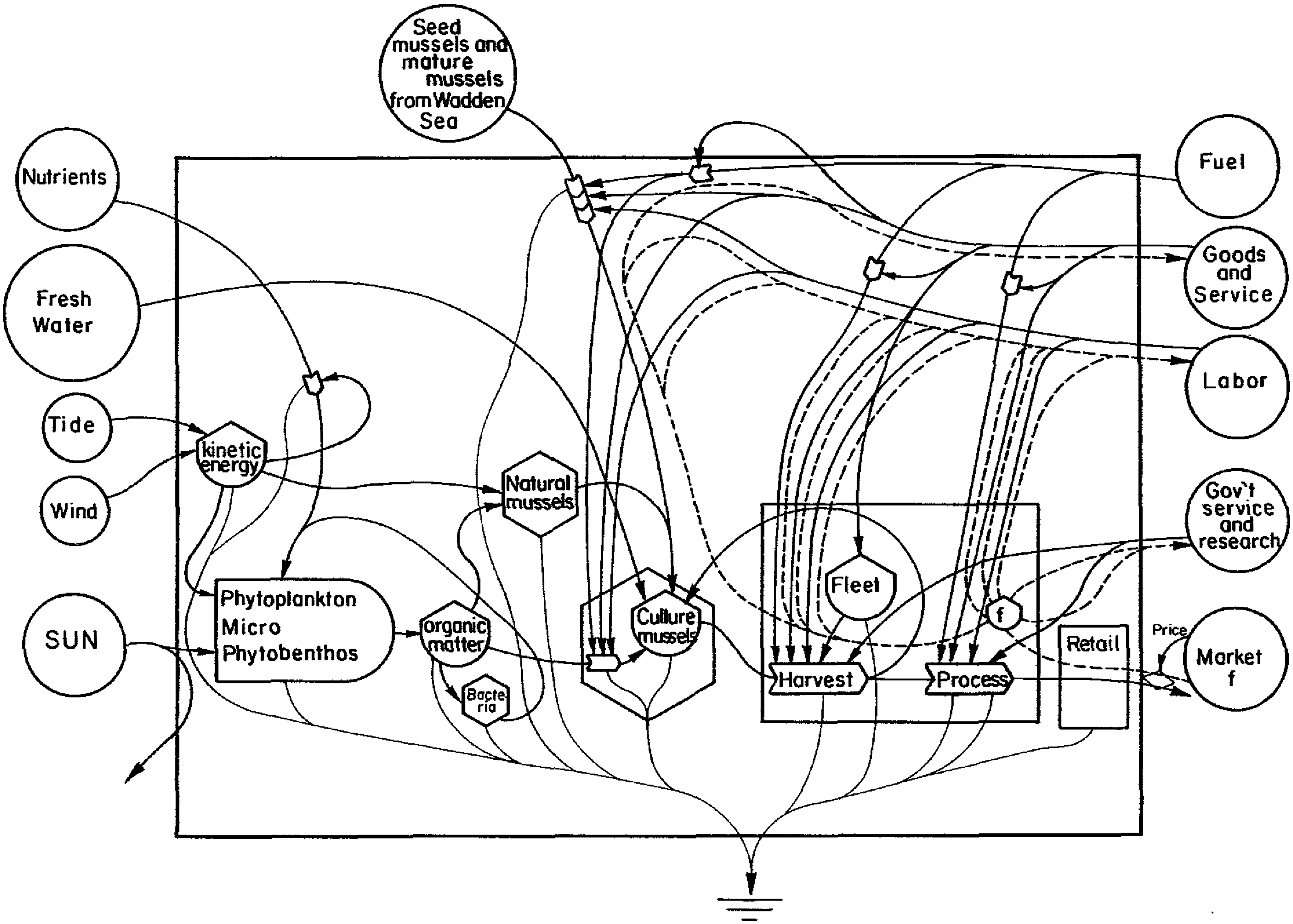

Figure 5. Oosterschelde Mussel Fishery.

Aggregated Diagram

An aggregated diagram (Figure 6) was drawn to consolidate and reduce the number of pathways to an essential minimum. The merging of subsystems and their flows presents a simplified picture of the most crucial subsystem and their interactions.

Outside energy sources were listed in order of quality (Tables 1-3) and shown in this order on the diagrams from left to right. High quality energies are those with more embodied energy per unit of actual energy. More diffuse, natural energies such as sun, wind, rain, tides, geologic uplift, etc., are followed by more concentrated and flexible sources (in terms of use) such as fossil fuels and goods and services. This hierarchy is shown spatially in Figures 3, 5 and 6 as the quality of the sources increases from left to right.

Energy Analysis Tables

The merged flows and the dollar flows associated with Figure 6 were listed and evaluated in Tables 1-3. Table 1 evaluates the inputs contributing emergy to the first stage, the production and collection of mussels from the Wadden Sea; Table 2 evaluates the second stage, wherein mussels are put into the Eastern Scheldt and collected again. Table 3 evaluates the processing of the mussels for the wholesale market and retail markets. Table 4 evaluates two major long term storages that contain and supply embodied energy, peat and fishermen's capital assets - boats.

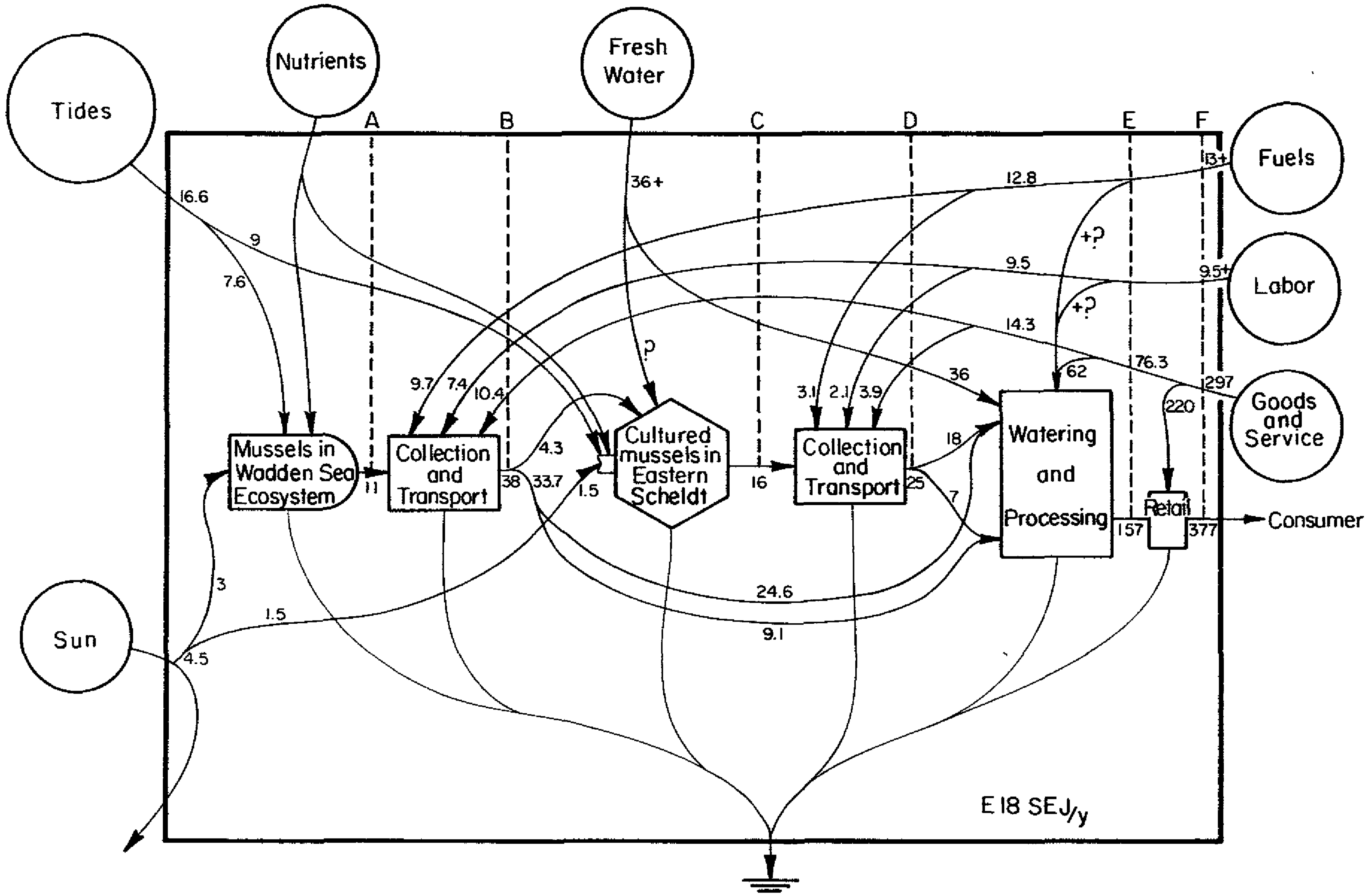

Figure 6. Aggregated diagram of a Dutch Mussel Fishery. Emergy flows are given in solar emjoules/year.

Using standard formulas of physics, chemistry and geology, the actual energy flow or storage for each item in Tables 1-4 was calculated in joules. Details are given in Table footnotes.

In the second column of the tables, energy transformation ratios taken primarily from Odum et al. (1983) were reported in solar equivalent joules per joule. These were previuosly determined by analysis of systems as is done for mussels in this paper.

In the third column of the tables embodied energies (emergy) was calculated by multiplying the joules (column 1) by the energy transformation ratio (column 2) associated with that element or process and reported in solar emjoules. The relative importance of a storage or flow may be indicated by its emergy.

The émergy evaluations were added to pathways on the overview diagram to provide perspective on the amounts and relative importance of various energy forms to an economy. Not all significant flows simply enter or leave the systems as imports or exports. There may be a drawdown of stored resources, which were included in the calculation of embodied energy which supports the economy. Examples are use of virgin timber and soils and depreciation of infrastructure.

The simultaneous generation by global atmospheric and oceanic systems of several types of natural energies creates the potential for double counting natural inputs which drive the economy. The energies of rain, wind and beach waves are products, of varying intensity, of the same original solar energy which accumulated predominantly over the ocean. To avoid "double counting" of the original solar joules, each of the solar-derived inputs was evaluated separately. But the largest one was chosen as the representaive natural input because it included the energy which generated the other natural inputs as a byproduct.

Table 1 evaluates the inputs that are embodied in mussels from the Wadden Sea. When these mussels are moved to the Eastern Scheldt to improve their quality, there are additional inputs as given in Table 2. Subsequently, when mussels of either group are processed to markets, there are additional inputs that are evaluated in Table 3. Finally, more handling and transport delivers mussels to retail markets. The last lines in each table (item 6, Table 1; item 12, Table 3; and items 18 and 19, Table 3) have the transformation ratio (transformities) as calculated from the inputs in that table.

Summary Diagram

A summary diagram, Figure 7, was then created which presents major inputs and the cumulative output. The diagram shows the stages involved when mussels from the Wadden Sea are passed through the Eastern Scheldt. Inputs are aggregated into two inflows. The lower quantity energy of "Renewable and Indigenous Resources" entering from the left is composed of: 1) renewable energy (sun and tides) 21.1 E18 SEJ/y, and 2) non-renewable, indigenous resource use (fresh water) 36 E18 SEJ/y. The higher quality energy entering from the top of the diagram, "Imported Resources," is composed of 1) imported fuels, 2) goods and imported services, and 3) labor, totaling 116 E18 SEJ/y.

Other ratios useful in overview were calculated at three stages in processing (Table 7) including the net energy yield ratio and the ratio of economic invested inputs to environmental inputs (investment ratio).

Table 1. Energy flows supporting mussels and use in the Wadden Sea subsystem.

Foot-note	Energy Type	Actual Energy J/y	Energy Transformation Ratio	Embodied Solar Energy E18 SEJ/y
1	Sunlight	3 E18	1	3.0
2	Tide	3.2 E14	23567	7.6
3	Fuels			
	a) Labor (1.17 E6 US $)		(2.23 E12 SEJ/US $)	2.6
	b) Natural input	1.35 E14	53000	7.1
4	Labor (3.3 E6 US $)		(2.23 E12 SEJ/US $)	7.4
5	Goods and Services (4.7 E6 US $)		(2.23 E12 SEJ/US $)	10.4
6	Mussel Yield from Wadden Sea	3.8 E13	1 E6	38.1

Footnotes to Table 1

1 Direct sunlight to Wadden Sea

Assuming that since Wadden Sea mussel fishery produces twice as many mussels as the Eastern Scheldt that twice the surface area was involved. Average insolation: 3.4 E9 $J/m^2/y$ (Braat in Odum et al., 1983)

(88 E3 ha)(1 E4 m^2/ha)(3.4 E9 $J/m^2/y$) = 3.0 E18 J/y

2 Tide

Total mussel production (1982-83): 781,478 mussel tons (W. Smit, 1984): av. production per hectare: 500 mussel tons (Abrahamson, pers. comm.); Area = production divided by acreage production per hectare = (781,478 mt)/(500 mt/ha) = 1574 ha; average Dutch tide amplitude: 2.4 m (Braat in Odum et al., 1983).

(1574 ha)(1 E4 m^2/ha)(706 tides/y)(0.5)$(2.4\ m)^2$(1.025 E3 kg/m^3)(9.8 m/s) = 3.2 E14 J

3 Fuels

Expenditure: 3254 E3 guilders = 1.17 E6 US \$ (W. Smit, 1984); Dutch national energy/\$ ratio: 2.23 E12 SEJ/US \$ (Braat in Odum et al., 1983); Fishing vessel diesel motor oil characteristics: 281 US \$/1 oil ton , 1 oil ton = 800 kg = 1000 l (Shell Oil Co., Rotterdam); Diesel oil actual energy: 34,030 kcal/gallon = 7,734 kcal/l (Odum et al., 1983b).

Labor: (1.17 E6 US \$)(2.28 E12 SEJ/US \$) = 2.6 E18 SEJ

Natural Energy: (1.17 E6 US \$)(1 ton/281 US \$)(1000 l/T)(7,734 kcal/l) (4186 J/kcal) = 1.35 E14 J/y

4 Labor

Wages/Social Security: 8348 E3 guilders = 3.01 E6 US \$, Travel expenses: 829 E3 guilders = 2.99 E5 US \$ (W. Smit, 1984).

(3.31 E6 US \$/y)(2.23 E12 SEJ/US \$) = 7.4 E18 SEJ/y

Footnotes to Table 1 (continued)

5 Goods and Services

All expenses in 1 E3 guilders; maintenance/repair of ships: 1895; Harbor/canal duties: 154; Insurance: 547; Navigation and deck equipment: 622; cost of sea-bed plots: 500; Interest: 3343; Fee for mussel trade organization ("Productschap"): 791; Depreciation: 4900; Other: 175 (W. Smit, 1984).

Total expenses = 1.3 E6 guilders = 4.7 E6 US $

(4.7 E6 US $)(2.23 E12 SEJ/US $) = 10.4 E18 SEJ/y

6 *Yield of Wadden Sea mussels*

Mature mussel yield ('82-'83): 781478 mussel tons = 7.8 E7 kg; seed mussel yield: 263,399 mussel tons = 2.6 E7 kg (W. Smit, 7984); total mussels = 1.04 E8 kg wet weight

Total embodied energy: 34.2 E18 SEJ (footnotes 1-5, Table 1);

Mussel flesh dry weight = (0.029)(whole weight including shell)

Actual energy = (0.029)(1.04 E8 kg)(3 kcal/g)

(1 E3 g/kg)(4186 J/kcal) = 3.8 E13 J

ETR = (38.1 E18 SEJ)/(3.8 E13 J) = 1.0 E6 SEJ/J

Table 2. Energy flows of the Eastern Scheldt subsystem.

Foot-note	Energy Type	Actual Energy J/y	Energy Transformation Ratio SEJ/J	Embodied Solar Energy E18 SEJ/y
7	Direct Sunlight	1.5 E18	1	1.5
8	Tides	3.8 E14	23567	9.0
9	Seed mussels	9.4 E12	4.55 E5	4.3
10	Fuel			
	a) Labor (3.7 E5 US $)		(2.23 E12 SEJ/US $)	0.8
	b) Natural	4.3 E13	53000	2.3
11	Labor (9.5 E5 US $)		(2.23 E12 SEJ/US $)	2.1
12	Goods and Services (1.74 E6 US $)		(2.23 E12 SEJ/US $)	3.9
13	Mussel yield, East. Scheldt*	1.4 E13	1.8 E6	23.9

* After passing Wadden Sea mussels through Eastern Scheldt.

Footnotes to Table 2

7 Direct Sunlight

Estuary area: 44,000 ha (Knoester, 1983); Annual solar energy: 3.4 E9 $J/m^2/y$

(44 E3 ha)(1 E4 m^2/ha)(3.4 E9 $J/m^2/y$) = 1.5 E18 J/y

8 Tides

Area elevated: 935 ha (Appendix I); tides per year: 706 (L. Braat in Odum et al., 1983); height: 3.4 m (calculated from tidal height distance curve of the Eastern Scheldt); density: 1.025 E3 kg/m^2; gravity: 9.8 m/s

(706 tides/y)(935 ha)(1 E4 m^2/ha)(0.5)$(3.4\ m)^2$(1.025 E3 kg/m^2)(9.8 m/s)

= 3.8 E14 J/y

9 Seed mussels

Total weight/y: 2.6 E7 kg (footnote 6); ETR: 9.1 E5 SEJ/J

Actual energy: (0.029)(2.6 E7 kg)(1 E3 g/kg)(3 kcal/g)(4186 J/g)

= 9.44 E12 J

Average spat/adult ratio = 2; therefore we assume greater spat mortality due to less embodied energy in proportion to this ratio. Therefore ETR for spat = 1/2 Wadden Sea mussel ETR = 4.55 E5 SEJ/J.

10 Fuel

Annual fuel expense (82-83): 1027 E3 guilders = 3.7 E5 US $ (W. Smit, 1984); 1982 diesel motor oil price: 281 US $/ton = 281 US $/1000 l (Shell Oil Co., Rotterdam); Diesel oil actual energy = 34,030 kcal/gal = 7,734 kcal/l (Odum et al., 1983b).

a. Labor (3.7 E5 US $)(2.23 E12 SEJ/US $) = 8.3 E17 SEJ/y

b. Natural energy

(3.7 E5 US $)(1000 l/281 US $)(7,734 kcal/l)(4186 J/kcal)

= 4.3 E13 J

Footnotes to Table 2 (continued)

11 Labor

Total costs in E3 guilders: Wages and social security:

2636 E3 Dutch guilders (W. Smit, 1984)

(2636 E3 guilders)(1 US $/2.77 guilders)(2.23 E12 SEJ/US $)

= 2.1 E18 SEJ/y

12 Goods and Services

Total costs in E3 guilders: maintenance and repair of ships: 598; Harbor and canal fees: 48; Insurance: 173; Naviagation and deck equipment: 197; Cost of seabed plots: 655; Interest: 1093; Fee for industry trade organization: 332; Other: 175; Depreciation: 1547 (W. Smit, 1983).

(4818 E3 guilders)(1 US $/2.77 guilders)(2.23 E72 SEJ/US $)

= 9.1 E18 SEJ/y

13 Mussel yield from the Eastern Scheldt

Total embodied energy of inputs: 23.9 E18 SEJ (footnotes 7-12); total yield of Eastern Scheldt mussels: 375,839 mussel tons = 1.09 E6 kg dry weight (W. Smit, 1984); actual energy of dry mussel flesh: 3 kcal/g (Odum, Et., 1971)

Total actual energy:

(1.09 E6 kg)(1 E3 g/kg)(3 kcal/g)(4186 J/kcal)

= 1.36 E13 J

ETR = (23.9 E18 SEJ)/(1.36 E13 J)

= 1.8 E6 SEJ/J

Table 3. Energy flows of mussel processing after harvest.

Footnote	Energy Type	Actual Energy J/y	Energy Transformation Ratio SEJ/J	Embodied Solar Energy E19 SEJ/y
14	Harvested mussels			
	Wadden Sea	3.8 E13	9.1 E5	3.4
	Eastern Scheldt	1.4 E13	3.3 E6	4.6
	Total (less 2.0 E19 SEJ for seed mussels)			6.0
15	Chemical purity of fresh water	2.3 E15	15423	3.6
16	Mussel trade costs			
	Fresh trade (11,812,055 US$)		(2.23 E12 SEJ/US$)	2.6
	Processed trade (16,019,089 US$)		(2.23 E12 SEJ/US$)	3.6
17	Unprocessed mussel yield	3.1 E13	3.13 E6	9.7
18	Processed mussel yield	1.1 E13	5.2 E6	5.9
19	Distribution Services			22.0
20	Mussel utilization by retail market		7.3 E6	37.7

Footnotes to Table 3

14 Harvested mussels from the eastern Scheldt and the Wadden Sea

Wadden Sea mature mussels = 81% of mature and seed mussel harvest (J. Smit, 1984); Actual energy of Wadden Sea mature mussels:

(0.81)(3.8 E13 J) = 3.07 E13 J (footnote 6); actual energy of eastern Scheldt mussels = 1.4 E13 J (footnote 13).

Since the embodied energy of Wadden Sea spats is already accounted for in the Wadden Sea mussel figure, the embodied energy of spats must be subtracted from the eastern Scheldt figure.

Eastern Scheldt embodied energy

= (1.4 E13 J)(1.7 E6 SEJ/J) = 4.3 E18 SEJ

2.38 E19 SEJ - 4.3 E18 SEJ = 1.95 E19

15 Chemical potential of all fresh water inputs

Volume of flow = 55 m^3/s (Knoester et al., p. 52)

(55 m^3/s)(3.16 E7 s/year) = 1.74 E9 m^3/year

Gibb's free energy of fresh water (G):

Chlorosity of estuary (av.) = 16.5 g/l (Knoester et al., p. 53)

Chlorosity of Volkerak = 7 g/l (Knoester et al., Fig. 2, pt. Z1)

$$G = \frac{(8.33\ \text{J/mole/degree})(300°\text{C})}{(18\ \text{g/mole})} \left[\log_e \frac{(1\ \text{E6 g} - 7000\ \text{g})}{(1\ \text{E6 g} - 16500\ \text{g})}\right]$$

= 1.33 J/g

(1.74 E9 m^3/y)(1 E6 g/m^3)(1.33 J/g) = 2.32 E15 J/y

Footnotes to Table 3 (continued)

16 Processing Costs

Total costs for mussels purchased from fishermen plus profit:

41,086,000 guilders = 14,832,490 US $ (W. Smit, 1984)

Roughly 20-35% of mussel harvest is processed, median figure 27% (Productschap, mussel fishery trade organization). The remaining 73% is sold fresh.

Fresh mussel trade ratio between selling and purchasing price: 69/33 (W. Smit, pers. comm.).

Fresh mussel trade receipts

= (0.73)(purchase price from fishermen)(69/33)

= (0.73)(14,832,490 US $)(2.09) = 22,639,773 US $

Fresh mussel trade costs = receipts - purchase price

= 22,639,773 - 10,827,717 = 11,812,055 US $

(11,812,055 US $)(2.23 E12 SEJ/US $) = 2.6 E19 SEJ

Processed mussel trade ratio between selling and purchasing price:

15.5/3,7 = 5 (W. Smit, pers. comm.)

Processed mussel trade receipts

= (0.27)(14,832,490 US $)(5) = 20,023,860 US $

Processed mussel purchase

= (0.27)(14,832,490 US $) = 4,004,772 US $

Processed mussel costs

= (receipts) - (purchase price) = 16,019,089 US $

(16,019,089 US$)(2.23 E12 SEJ/US $) = 3.6 E19

Footnotes to Table 3 (continued)

17 Unprocessed (fresh) mussel yield

Total embodied energy of unprocessed mussels:

(0.73)(embodied energy of Wadden Sea and Eastern Scheldt mussels)

+ (0.73)(chemical purity energy) + (processing costs of fresh mussels)

= (0.73)(6.2 E19 SEJ) + (0.73)(3.6 E19 SEJ) + (2.6 E19 SEJ)

= (4.5 E19 SEJ) + (2.59 E19 SEJ) + (2.6 E19 SEJ)

= 9.69 E19 SEJ

Total actual energy of fresh mussels:

(0.73)(115,731,700 kg total harvest whole weight)(0.17 wet flesh wt/whole weight)

(0.17 dry flesh/wet flesh weight)(3 kcal/g dry weight)(1E3 g/kg)(4186 J/kcal)

= 3.1 E13 J

ETR = (9.69 E19 SEJ)/(3.1 E13 J)

= 3.13 E6 SEJ/J

18 Processed mussel yield (cooked mussels)

Total embodied energy of processed mussels:

(0.27)(embodied energy of Wadden Sea and Eastern Scheldt mussels) + (0.27)

(chemical purity energy) + (processing costs for processed mussels)

= (0.27)(6.2 E19 SEJ) + (0.27)(3.6 E19 SEJ) + (3.2 E19 SEJ)

= 5.85 E19 SEJ

Total actual energy of processed mussels:

(0.27)(115,731,700 kg total harvest whole weight)(0.029 dry weight/

whole weight)(3 kcal/g dry wt)(1 E3 g/kg)(4186 J/kcal)

= 1.13 E13 J

ETR = (5.85 E19 SEJ)/(1.13 E13 J) = 5.2 E6 SEJ/J

Footnotes to Table 3 (continued)

19 Distribution services

Yield and cost to final consumer (payment for all goods, services, labor)

(1.153 E8 kg)(2.6 guilders/kg)(2.2 E12 SEJ/$)(2.16 guilders/$US)

= 306 E18 SEJ/y

Goods and services utilized for distribution

(Total yield and cost to final consumer)-(Goods + Services embodied in Watering and Processing)-(Goods + Services + Labor embodied in Collection and Transport of mussels from Wadden Sea and Eastern Scheldt)

(306 E18 SEJ/y)-(62 E18 SEJ/y)-(23.8 E18 SEJ/y)

= 220.2 SEJ/y

20 Mussel utilization by Retail Market

(Total emergy in wholesale mussels)+(Total emergy in Distribution Services)

= (157 E18 SEJ/y)+(220 E18 SEJ/y) = 377 E18 SEJ/y

ETR (transformity)

Total actual energy in mussels: 5.2 E13 J/y(footnote 6 Table 1, footnote 13 Table 2)

Total emergy in retail mussels = 377 E18 SEJ/y

ETR = (377 E18 SEJ/y)/(5.2 E13 J/y) = 7.3 E6 SEJ/J

Table 4. Energy storages in the eastern Scheldt and the mussel fishing industry.

Footnote	Type of Energy	Actual Energy J/y or tons	Energy Transformation Ratio SEJ/J	Embodied Solar Energy SEJ
1	Peat in substrate	2.7 E16	15432	4.2 E20
2	Steel in fishing fleet	(5417 tons)	(1.78 E15 SEJ/T)	9.6 E18

Footnotes to Table 4

1 Peat in the substrate of the watering beds

Peat formation: approximately 2400 B.C. - 900 A.D. ≅ 3300 years formation time (K. Jelgersma, Rijks Geologische Dienst, Haarlem, Netherlands); Annual rainfall: 739 mm (DIHO, 1981); total area of peat beds: 250 ha

(3300 years)(250 E4 m^2)(0.739 m)(4.94 J/g)(1 E6 gm^3)

= 2.74 E16 J

2 Steel in fishing ships

Total volume (L x W x D) of fishing vessels: 36,116 m^3 (Ministerie van Landbouw en Visserij, 1984); formula for steel weight of ship: 15% of ship volume (Rinus Kooiman, shipbuilder, Yerseke, Netherlands)

(36,116 m^3)(0.15) = 5417.4 T

Embodied energy of steel: 1.78 E15 SEJ/T (Bosch in Odum et al., 1983)

Table 5. Summary of energy flows.

	Footnote	A Wadden Sea production	B Collected and transported	C Yield from Eastern Scheldt	D Collected and transported	E Processed or wholesale	F Retail
		Stage in Figs. 6 and 7					
1	Energy E13 J/y	3.8	3.8	1.4	1.4	5.2	5.2
2	Emergy E18 SEJ/y	11.0	38.0	16.0	25.0	157.0	377.0
3	Transformity E6 SEJ/J	0.3	1.0	1.1	1.8	3.0	7.3
4	Cumulative net energy yield ratio	--	1.4	5.1	1.6	1.6	1.2
5	Cumulative economic/ environment ratio	--	2.5	0.3	1.7	1.7	5.6
6	Macroeconomic value million $/y	4.9	17.0	6.7	11.2	70.4	169.0
7	Price 1980 $/kg				$.25	$.81	$1.2
8	Microeconomic value million $/y	0	--	--	28.8	75.5	138.0

Footnotes to Table 5

1 All actual energy figures based on total mussel harvest weight (dry) and energy per dry weight (Odum, 1971). See, for example, footnote 6, Table 1.

2 See Tables 1-3 for embodied energy calculations.

3 Energy transformation ratios calculated as the solar equivalent joules (SEJ) per joule (J) at each of the various points in Figure 6.

4 Net Energy Yield Ratio indicates net energy if the yield (Y) divided by the high quality feedback (F) exceeds 1. If no high quality feedback (fossil fuel, labor, goods and services) are used in a process then the yield ratio is not applicable, as in points A and C.

Calculation at point E

(157 E18 SEJ)/(62 E18 SEJ)

= 2.5

5 Investment Ratio for a process is not applicable if no high quality feedback is involved, as in points A and C. Calculation at point E

(62 E18 SEJ)/[(36 + 43 + 16)x(1 E18 SEJ)]

= 0.65

Note the inclusion of fresh water (36 E18 SEJ) as a natural energy flow in the denominator.

6 Macroeconomic value:

Contributions to GNP calculated at each point by dividing the total embodied energy at that point by the Dutch national energy/1980 $ ratio: 2.23 E12 SEJ/$ (L. Braat in H.T. Odum et al., 1983).

7 Prices (Smit and Smit, 1983)

8 Microeconomic value as price multiplied by mussel yields and expressed in 1980 U.S. dollars.

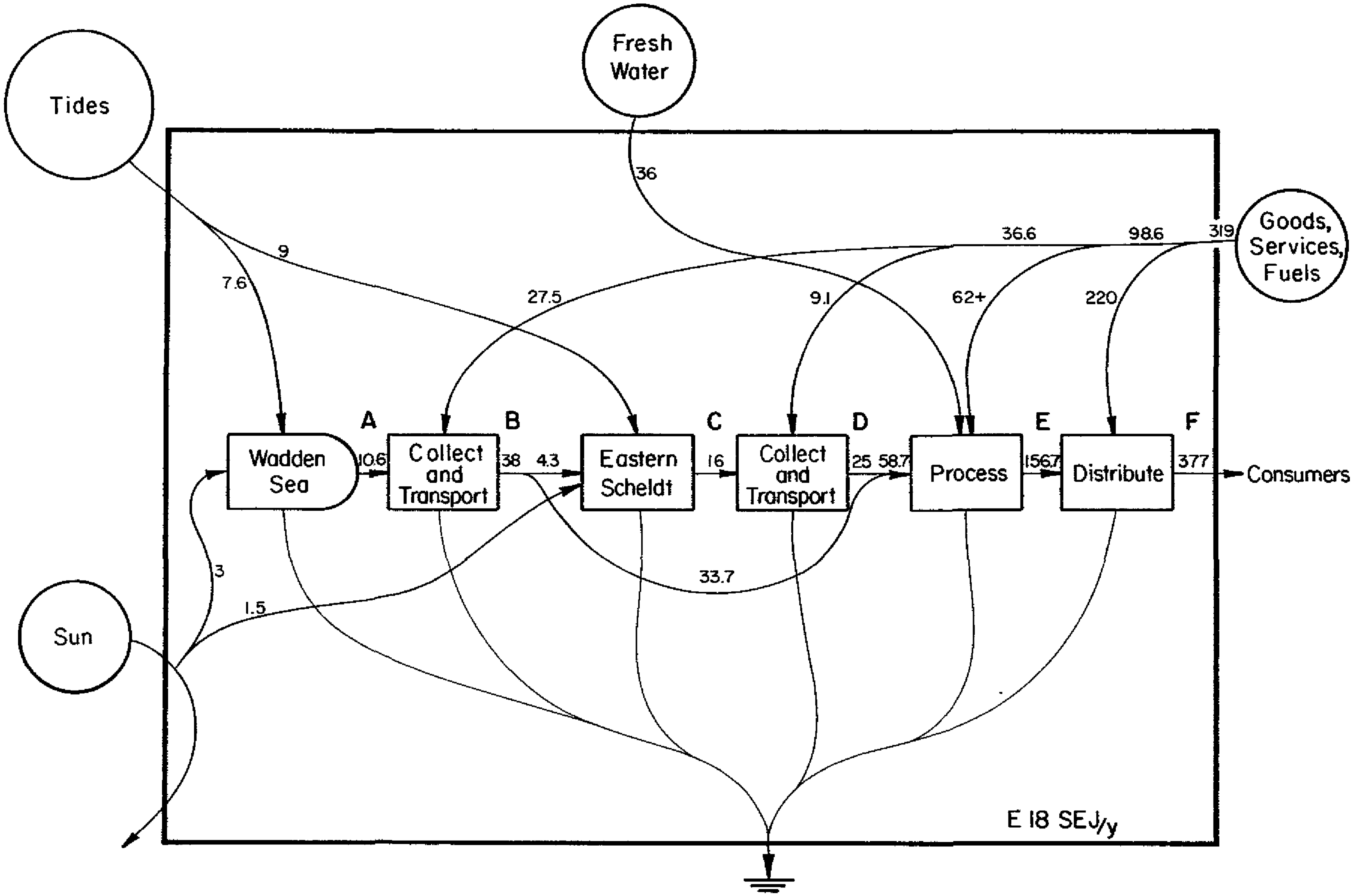

Figure 7. Summary diagram of mussel industry giving estimate of emergy flow in SEJ/y.

Table 6. Summary of figures based on Figure 7.

Footnote	Description	Item
1	Total renewable and indigenous resources	57.1 E18 SEJ/y
2	Total purchased resources	319 E18 SEJ/y
3	Total yield of marketable mussels	377 E18 SEJ/y
4	Energy transformation ratio* of retail yield	7.3 E6 SEJ/J
5	Net energy yield ratio	1.2
6	Economic/environmental (investment) ratio	5.6
7	Macroeconomic value (1978 $)	169 E6 $/y
8	Microeconomic value (1980 $)	120 E6 $/y

* Transformity

Footnotes to Table 6

1 Total renewable and indigenous resources (in E18 SEJ): sunlight (4.5), tides (16.6), fresh water (36);

Total = 57 E18 SEJ

2 Total imported resources (in E18 SEJ):

Collection and transport: fuel (12.8), labor (9.5), goods and services (297),

Total = 319 E18 SEJ

3 Total yield of marketable mussels = sum of all natural plus imported resources

4 Energy transformation ratio: (377 E18 SEJ)/(5.2 E13 J) = 7.3 E6 SEJ/J

5 Net energy yield ratio: (377 E18 SEJ)/(319 E18 SEJ)

= 1.2

6 Investment ratio: (319 E18 SEJ)/(57 E18 SEJ)

= 5.6

7 $\frac{(377\ \text{E18 SEJ/y})}{2.23\ \text{E12 SEJ/1978 US \$}} = 169\ \text{E6 US \$}$

8 $\frac{(2.6\ \text{guilders/kg})(1.15\ \text{E8 kg/y})}{(2.5\ \text{guilders/1980 US \$})} = 120\ \text{E6 US \$}$

Table 7. Energy investment ratios for various agroecosystems (after Odum, 1984).

Footnote	System	Energy investment ratio
1	New Zealand radiata pine	0.9
2	New Zealand fodder beets	6.2
3	U.S. corn	12.7
4	Subsistence corn	0.004
5	U.S. honey	0.14
6	New Zealand wool and meat	4.9
7	Louisiana shrimp	2.7
8	Dutch mussels - wholesale	1.7
	retail	5.6

Footnotes to Table 7

1-6 Footnotes 1-6 see Table 3.3 in Odum (1984).

7 Using modified data from Fonyo (1983); total purchased energy (fuel and overhead costs) = (2.21 E23 SEJ/y + 1.51 E23 SEJ/y) = 3.72 E23 SEJ/y; total renewable energies = total chemical potential energies embodied in the outflow of the Mississippi River = (6.8 E12 SEJ/m^2)x(2.04 E10 m^2) = 1.39 E23 SEJ/y

$$\frac{3.72 \text{ E23 SEJ/y}}{1.39 \text{ E23 SEJ/y}} = 2.7$$

8 See Table 6, footnote 6

Table 8. Sea fishery efficiencies in actual energy terms. Fossil fuel input per protein output (after Pimentel and Pimentel, 1979).

Footnote	Seafood type	Kcal fossil energy input/ Kcal output of protein
1	Herring	2
2	Perch, ocean	4
3	Salmon, pink	8
4	Cod	20
5	Tuna	20
6	Mussels	20.5
7	Haddock	23
8	Halibut	23
9	Salmon, king	40
10	Shrimp	150
11	Lobster	192

Footnotes to Table 8

Footnotes 1-5, 7-11 see Pimentel and Pimentel, 1979, Table 9.2, p. 108.

Footnote 6

A. Total fossil fuel energy inputs:

a. Wadden Sea (Table 1): 1.35 E14 Joules = 3.2 E10 Kcal

b. Eastern Scheldt (Table 2): 4.3 E13 Joules = 1.0 E9 Kcal

c. Processing

energy costs = 11% of processing costs

(0.11)($27,831,144)(1 ton fuel/$281)(1000 1/1 ton)(7,734 Kcal/1)

= 8.4 E10 Kcal

d. Fossil fuel embodied in fleet equipment

Total fleet weight: 5417.4 tons (Table 4, footnote 2)

Total number of ships in fleet: 102 (N.J. de Niet, Ministrie van Landbouw en Visserij, pers. comm.). Average weight per ship = (5417.4T)/(102 ships) = 53.1 T per ship. Assuming that Dutch fishing vessel manufacture is similar to US and using figures from Rochereau, 19   for fishing vessels with a GRT (gross registered tonnage) of 40 tons, the energy embodied is 278 E9 Joules per ship or 2.84 E13 Joules for the whole fleet = 6.8 E9 Kcal.

Total = 6.8 E9 Kcal + 3.2 E10 Kcal + 1 E9 Kcal + 8.4 E10 Kcal

= 1.24 E11 Kcal

B. Total Kcal output of protein

Total harvest = 115,731,700 kg (Table 3, footnote 17)

Protein content: 0.6, Calorie content: 3 Kcal/g dry weight (Odum, E., 1971)

(115,731,700 kg whole weight)(0.0289 kg dry wt/kg whole weight)

(1 E3 g/kg)(0.6 pro ein)(3 Kcal/g dry weight)

= 6.04 E9 Kcal

C. Fossil fuel Kcal input/Kcal protein output

8.4 E10 Kcal/6.04 E9 Kcal = 20.5

Table 9. Net energy yields in foreign trade of commodities by developed nations (after Odum, 1984).

Footnote	Item	Price per unit in 1978 US $	Embodied energy to purchaser per embodied energy paid
1	Corn	$ 200 T^{-1}	2.7
2	Mutton	$ 2.00 kg^{-1}	9.5
3	Wool	$ 2.20 kg^{-1}	15.0
4	Plantation wood	$ 5.70 T^{-1}	7.5
5	Honey	$ 1.17 kg^{-1}	3.5
6	Shrimp	$ 2.36 lb^{-1}	10.1
7	Wholesale mussels sold within Netherlands	$ 0.50/kg	1.22
8	Retail mussels sold within the Netherlands	$ 1.20/kg	1.4
9	Fresh mussels (purchased by France from the Dutch mussel fishery)	$ 0.28 kg^{-1}	2.1
10	Unprocessed fresh mussels (purchased by Belgium)	$ 0.50 kg^{-1}	6.1

Footnotes to Table 9

Footnotes 1-5: see Odum, H.T. (1984)

6 Using data from Fonyo (1983), Table 1: a) average price per pound of shrimp paid by wholesalers to fishermen was $2.36/lb; b) annual harvest per ship averaged for 3 vessel size classes:

40,038 lbs; c) total embodied energy of annual shrimp harvest per ship for 3 vessel size classes: 2.65 E18

SEJ/yr; d) average annual revenue: $101,153.67

Embodied energy paid for shrimp:

(101,152.67 US $)(2.6 E12 SEJ/US $) = 2.63 E17 SEJ

Embodied energy received per embodied energy paid:

2.65 E18 SEJ/2.63 E17 SEJ = 10.1

7 Emergy received for emergy paid

(157 E18 SEJ/y)/[($0.5/kg)(1.15 E8 kg/y)(2.23 E12 SEJ/$)]

8 Energy received for emergy paid

(377 E18 SEJ/y)/[(120 E6$/y)(2.23 E12 SEJ/$)]

= 1.4

9 Emergy per kg

payment = ($.28/kg)(2.23 E12 SEJ/$) = 6.4 E11 SEJ/kg

received = (1kg) [(157 E18 SEJ/y/1.15 E8 kg] = 1.37 E12 SEJ/kg

Received/Payment = 2.1

10 Embodied energy received per embodied energy paid by the Dutch or the Belgians

Total fresh harvest weight: 1.44 E7 kg (see footnote 8);

Total embodied energy received: 9.7 E19 SEJ (Table 3, footnote 17);

Dutch embodied energy/US $ ratio: 2.2 E12 SEJ/US $ (L. Braat in Odum et al., 1983a); Price paid by Dutch or Belgians in 1978: 1.09 guilders/kg (W. Smit, pers. comm.)

Embodied energy paid for mussels by Dutch or Belgians

(1.15 E8 kg)(1.09 guilders/kg)(1 US $/2.16 Dutch guilders) (2.2 E12 SEJ/US $)

= 1.6 E19 SEJ

Embodied energy received/embodied energy paid

= 9.7 E19 SEJ/1.6 E19 SEJ

= 6.1

DISCUSSION

As might be expected in a developed nation, economic contributions facilitated by humans attracted to match those of nature outweigh those of nature in the Dutch mussel fishery (Figure 6). At the wholesale auctions some 63% (98.6 E18 SEJ) of the energy required for operation comes from human directed energy inputs such as fossil fuels, labor and goods and services, and some 37% (57 E18 SEJ) comes from natural inputs such as sunlight, nutrients, tides and the chemical purity of water. As measured by emergy, the two single most important contributions appear to be labor (30%) and the fresh water entering mostly through the Volkerak (23%).

Human inputs predominate in the early stages of mussel culture and again in final distribution to retail outlets. Human directed energies contribute 63% of the energy value of mussels harvested from the Wadden Sea or the Eastern Scheldt with goods and services, fuels and labor contributing 25%, 22%, and 16.4%, respectively. The natural inputs of sunlight, nutrients and tides contribute 7.8% and 29%, respectively.

In the processing of the mussel fishing industry natural contributions outweigh those of humans by 60% to 40%. This is mainly due to the large amount of energy embodied in the mussels themselves (37% of all inputs) and the sizeable input of the chemical purity of fresh water (23% of all inputs). The only human input of any significance in this sector is labor (26% of all inputs).

Comparison of energy transformation ratios (transformities) of different foods can indicate their relative qualities as defined by the energy used in their production. On this basis unprocessed mussels (Table 3, footnote 17) are similar to calf meat (Odum et al., 1983b), and processed mussels (Table 3, footnote 18) are comparable to other processed meat foods, including shrimps harvested from the Gulf of Mexico, whose ETR is about 2.6 E6 SEJ/J (Fonyo, 1983). This suggests that though mussel fishing is energy intensive it still may prove as good an energy bargain as certain types of coastal fishing.

Initial efforts of cultivation and harvesting involve a higher proportion of natural energy than the final work of processing. In the former case feedback of human directed energies amplify natural energy contributions to the economy by an average of 2.4 (compare ratios B/A and D/C in Table 5). The processing sector appears to amplify its incoming energies by a factor of 2.6 (ratio E/(D+B) in Table 5).

Agricultural ecosystems of roughly similar size are compared in Table 7, though U.S. corn may be more of a national class than a regional class enterprise. Dutch mussels, when processed to retail market, involve a similar economic investment ratio (5.6) as compared with New Zealand sheep meat (4.9) and Louisiana shrimp (6.3-17.9).

Future studies which include the energy costs of transportation from packer (processor) to retailer may find such shipping costs to be highly significant. Trucking and rail expenses may have prevented mussels from being a common food item far from European coasts where competition with local cheap protein sources, such as pork, is intense. Such shipping expenses are exacerbated by the relative fragility of mussels which can be kept alive for only 3-5 days after leaving marine conditions and require much transportation space in shell form. The European market for mussels is limited to coastal areas and has only increased during times of general lack of animal protein (Smit and Smit, 1983). The current ease of substitution of other protein sources has prevented anything but very slow increase in demand for mussels. And, since a 10% increase in production can mean a 15% decrease in price per mussel (Smit and Smit, 1983), there is a counter pressure to increased investment in mussels in the absence of higher demand.

A net energy yield ratio of 1.6 (Table 6) indicates that the Dutch mussel fishery contributes more to the general economy than either industrial corn (1.09) or New Zealand sheep (1.27). Such food sources, which don't require so much fossil fuel inputs, may appear more attractive in the future. Approximately 13% of all energy inputs come directly from fossil oils, and the fossil fuel subsidy of cheap oil which keeps European industrial products relatively cheap must also be acknowledged; the mussel fishing fleet is built and maintained with such products.

The attractiveness of mussels as an investment or as a source of animal protein can be affected by oil price fluctuations. For such times as fossil fuel stocks are plentiful enough to drive mechanized marine fleets it may be useful to consider marine protein sources based on the fossil fuel input efficiency. Table 8 shows that when compared with many sea fish, mussels appear to be a protein source with a relatively low fossil fuel investment, roughly the same as cod or tuna.

Another challenge to the Dutch mussel fishery has been the cheaper mussels produced in France. While more than half of Dutch mussel production goes to Belgium whose coasts are not mussel producing, a large fraction also is imported by France where prices are driven down by cheaper local mussels. The "standing" culture using poles in area of less sediments by the French mussel industry does not incorporate as much sediment removal or cleaning since the sea bed is not employed as a substrate. The pole culture is less fuel intensive since there is no serial deposition and transport of mussels from sea bed to sea bed, and manpower is emphasized (Smit and Smit, 1983). Also, since the French mussel is ready-for-consumption, the growers can sell directly to wholesalers or retailers without the intermediate step of packers.

Emergy Advantages in Trade

Table 9 lists the net emergy yields to buyers with a low energy dollar ratio such as the USA or West Germany. In all cases the ratio is greater than one, since the buyer only pays for service but receives the product, which also has energy of environmental work as well.

In Table 9, items 7 and 8 contrast the buying power of the Belgians and the French for the same product, the Dutch mussel. The French receive nearly twice the embodied energy in relation to their payment than do the Belgians. This might be attributed to the unique French environmental conditions and aquaculture which produces cheaper mussels, and allows the French to pay less for Dutch mussels. Thus, natural energy subsidies and cultures which take advantage of them stimulate the local economy by providing cheaper products and allowing more favorable exchange terms with foreign economies. The Belgians who do not have the environmental conditions for cheap mussel culture must pay higher prices and receive less embodied energy in the exchange.

CONCLUSION

The Dutch mussel fishery appears to be a fairly industrialized operation with 60-84% of its emergy from human directed energy inputs. The product is equivalent in quality (transformity) to other popular meats.

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