PROGRESS REPORT

NSF GH 43

"The Effective Uses of the Marine Resources of the Santa Barbara Area"

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TABLE OF CONTENTS

Fishes of the Santa Barbara Kelp Forest

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Introduction

Beds of giant kelp off Santa Barbara, California provide cover and food for complex animal communities containing several important sport fishes. Although more than 120 species of fish inhabit the southern California kelp beds, however, many are casual visitors from other areas (Quast, 1968b). Barracuda, yellowtail, and white sea bass, for example, orient to the periphery of the bed, where they enter an important sport fishery. The Santa Barbara fish fauna is a combination of northern, southern, and wide-ranging species, many fluctuating in abundance with the cooling trends, warming trends, and water-mass changes that distinguish the ecologically transitional Santa Barbara region (Hubbs, 1948; Quast, 1968a). With summer warming, migratory fishes like the bonito and barracuda enter the game fishery about the kelp beds as they follow the warmer water northward in search of forage fishes like the anchovy. Resident surface game fishes of the kelp, primarily the kelp bass, *Paralabrax clathratus*, implement this fishery of the kelp fringe. The much prized California halibut, *Paralichthys californicus*, also reacts to seasonal change and enters the summer sport fishery.

Resident populations of smaller fishes remain active in and about the kelp beds all year (Ebeling *et al.*, 1970). The olive rock fish *Sebastodes serranoides*, for example, replaces the kelp bass in the northern part of its range above Point Conception north of Santa Barbara. Other rock fishes and seaperches provide sport for kelp-bed anglers. Quast (1968b) studied many of these kelp-bed fishes. He noted the extensive overlap of the rocky-inshore and kelp communities with the surrounding level bottom communities, which were recently sampled off Santa Barbara following the oil spill of 1969 (Ebeling *et al.*, 1970). Both studies provide valuable supplements to the present and proposed investigations of fish communities in and about the Santa Barbara kelp. Relationships of these investigations with the fishery are emerging in multivariate analyses of resident fish abundances, catches per angler effort, and many other variables of the local marine system.

Ecological studies form the bases for applied research into the effects of pollution, overfishing, etc. Fishes have evolved specializations to live in certain habitats and exploit different resources in their own ways. Any artificial change in the environment, such as an influx of industrial wastes, therefore, will upset the fish's niche or fish-environmental relationship, a delicate balance maintained by natural selection. But are the observed variations in composition and abundance of fish communities due to artificial pollutants or to natural climatic fluctuations? In a transitional zone such as the marine littoral off Santa Barbara, the seasonal changes in the ecosystem must be distinguishable from man-made alterations before pollution damage can be measured (Ebeling *et al.*, 1970). The structure of a fish community should be understood before any subtle or long-term pollution damage can be detected and assessed. The main difficulty in evaluating possible effects of the recent oil spill on local fish communities was a lack of extensive observations of the composition of fish communities prior to the spill.

With last year's Sea Grant support (GH 43), we initiated systematic, well-organized, and quantitative analyses of the Santa Barbara kelp beds as a habitat for fishes. We hope to describe and analyze this still relatively unspoiled system before another major accident of pollution, increasingly probable as our industrial community rapidly expands. Local commercial and sport fishermen have become interested in our studies as they have become more and more aware of the disruptive contribution of pollution, seasonal change, and overfishing to fluctuating catch rates. For example, Mr. Italo Castagnola, a local commercial fisherman, regularly seeks advice on predicting catches relative to seasonal changes of conditions.

The objectives of this continuing study are: (1) to describe the ecological groups of fishes in the kelp beds (communities and concourses) and to find out how they relate to the environment as a whole system; then, (2) to investigate particular interactions suggested by an initial unified view of the entire system. For example, if an initial multivariate analysis of the 80 variables of fish abundances and other environmental characteristics measured resolves a factor dominated by increasing numbers of bottom invertebrates and greater bottom relief, we can ask why certain fishes but not others are associated with this factor. This will provide the insight to pursue particular studies of eating habits and utilization of cover. Is the rocky substrate or kelp itself of primary importance to the prevalence of these fishes and the maintenance of this segment of their ecosystem? Similarly a seasonal factor with components of water temperature may suggest metabolic experiments to find if some species are more sensitive to sudden temperature changes than others and why the summer sport fishery often fluctuates erratically. It will be interesting to see which factor correlates with the parameter of oil pollution and if it is a positive or negative influence on the array of variables composing the factor. Before the inception of the current studies, we knew very little about the general organization of the local subtidal ecosystem and how it interacts with the island sport fisheries.

Data processing

The present availability of high speed computers allows the profitable use of multivariate statistical models in ecological analyses (e.g., Ebeling et al., 1970a). We must examine as a whole system the interactions of many variables in the environment, from physical variables like temperature and pollution to biological variables like species diversity and food availability. Factor analysis provides such a synthesis, empirically justifiable, of the physical and biological elements in the system (Sokal and Daly, 1961). Intercorrelations among all variables are partitioned into factors, which imply causal arrays. The environment influences the habits and distribution of its occupants and the factors suggest how. For example, to investigate the ecology of the kelp bass most profitably, we first examine the array of variables composing the factor that also includes the variable of kelp-bass abundance. Presumably, this array will include other species in the bass community along with the physical variables that may control this community. These particular variables, therefore, comprise an intercorrelated subset within the set of all 80 variables measured: abundances and orientation of all observed species at various times, localities, and seasons; physical, chemical, and topographical parameters such as temperature, depth, turbidity, substrate, wave height, weather, cover, etc.; and others such as standing crop, food availability, sport fish catch, and pollution. When intercorrelated and resolved into factors, these variables should pinpoint specific questions, which can be later answered by controlled observation and laboratory experiment.

Procedure on station

Previous studies of kelp-bed communities involved hard and time-consuming work: e.g., the laying and maintaining of transect lines, setting buoys to locate permanent stations, instant underwater identification of fish species, replication of transect dives, long and arduous training, etc. (Quast, 1968c). The present analytical method of multivariate analysis, however, obviates the laborious control of environmental variables. That is, the locality, substrate, and kelp cover themselves are variables and are scored for each station (dive), chosen more or less at random. We may return to the same spot only by chance, and only two conditions control selection of stations: habitat representation and water clarity (if a choice must be made between two localities within a given area, we choose the one with clearest water).

Film strips obviate the difficulties of instant underwater identifications and abundance estimates. Line transects are replaced by 15-minute film strips taken by a SCUBA diving team, one diver operating the camera, the other scoring habitat type on a slate that simulates the first of a series of data sheets. This first sheet contains observations of the subset of in situ variables of the environment. The white reverse side of the slate is a reference to visibility at depth. The photographer swims at a slow and constant speed, remaining over the same bottom type at a constant depth. Pointing the camera forward, he "pans" it in a slight arc, filming a progressing zone about 6-10' wide.

During this dive, the boat tender completes a second data sheet of surface variables: depth, date, time, sea conditions, presence of bait fish, oil contamination, Secchi disc turbidity, temperature, salinity, plankton volumes, etc. If two film strips are taken during one dive, one set of surface observations serves two stations (cases), so that all rows of the final data matrix can be completed.

On a third data sheet, we later record observations of "remote" variables measured by others at about the time of the dive: relative humidity, catch per angler of sport fishes from commercial boats, standing crop of phytoplankton (chlorophyll a etc.), concentration of nutrients, barometric pressure, wind velocity and direction, phase of moon, etc. This subset may also complete more than one row, each for a 15-minute film strip.

On the fourth data sheet, we record fish abundances by species as we later view the film strips in slow motion. Although the camera field is narrower than the human visual field, film identifications can be rechecked if necessary and the numbers of individuals of the different species can be counted at leisure as the film is slowed or stopped. Therefore, the photographer need not necessarily be an expert at fish identification. Ichthyological novices can replace professionals if need be because the films provide permanent records of actual occurrences. The data sheet can be corrected upon review of the film strip. Precise numbers of individuals are obviously easier to count on a film than on locality underwater, where the fish dart quickly in and out of the visual field.

Preliminary results

To date, we have taken 26 film strips from 19 different localities. The technical problems encountered earlier have been largely overcome. High speed black and white films vividly record detail in shaded water under the kelp canopy on dark days, while color film records lighter areas more completely. Our new back-up camera has eliminated delays due to camera repair. Sampling effort is controlled by using standard film cartridges.

A preliminary analysis of the first 26 data sets indicates that this relatively simple and rapid method of cinematic recording yields the same relative species frequences as the more tiresome method of Quast (1968c) (Fig. 1). When we, like Quast (1968b), plotted the cumulative percentage of 57 species sighted in a series from the most to least abundance (horizontal axis in Fig. 1) vs. the percentage of the 26 film strips containing the species, the resulting lognormal curve (solid line) resembles Quast's (dashed line). A rank correlation test between the two sets of coordinates revealed no significant difference between the relative commonness of the species in the two arrays, even though Quast's observations were made off San Diego. The apparent coincidence of the two sets indicates that the comparatively simple film-strip recording provides an adequate measure of the relative commonness of overt kelp-bed fishes, as seen by SCUBA divers.

For a preliminary test of the multivariate method of assembling the variables into meaningful arrays, 28 of the 80 total variables were selected for factor analysis with rotation to simple structure (Sokal and Daly, 1961). Because the number of variables should not greatly exceed the number of cases (set of observations/station), the 26 cases recorded to date precluded a more extensive analysis. The four rotated factors resolved, however, are meaningful within this limited 28 by 26 system of observations (Table I). The loadings ("correlations") of the variables on the factors indicate the relative "importance" of the variables to the factors. (Variables with loadings less than an absolute value of .50 on a scale of 0 - ±1 were empirically adjudged "non-significant.") But be mindful of the limitations of the system when translating the arrays of factor loadings into working hypotheses. The problem is analogous to solving a jig-saw puzzle with but a few peices. This factor analytic model may allow only a partial arrangement of 28 peices

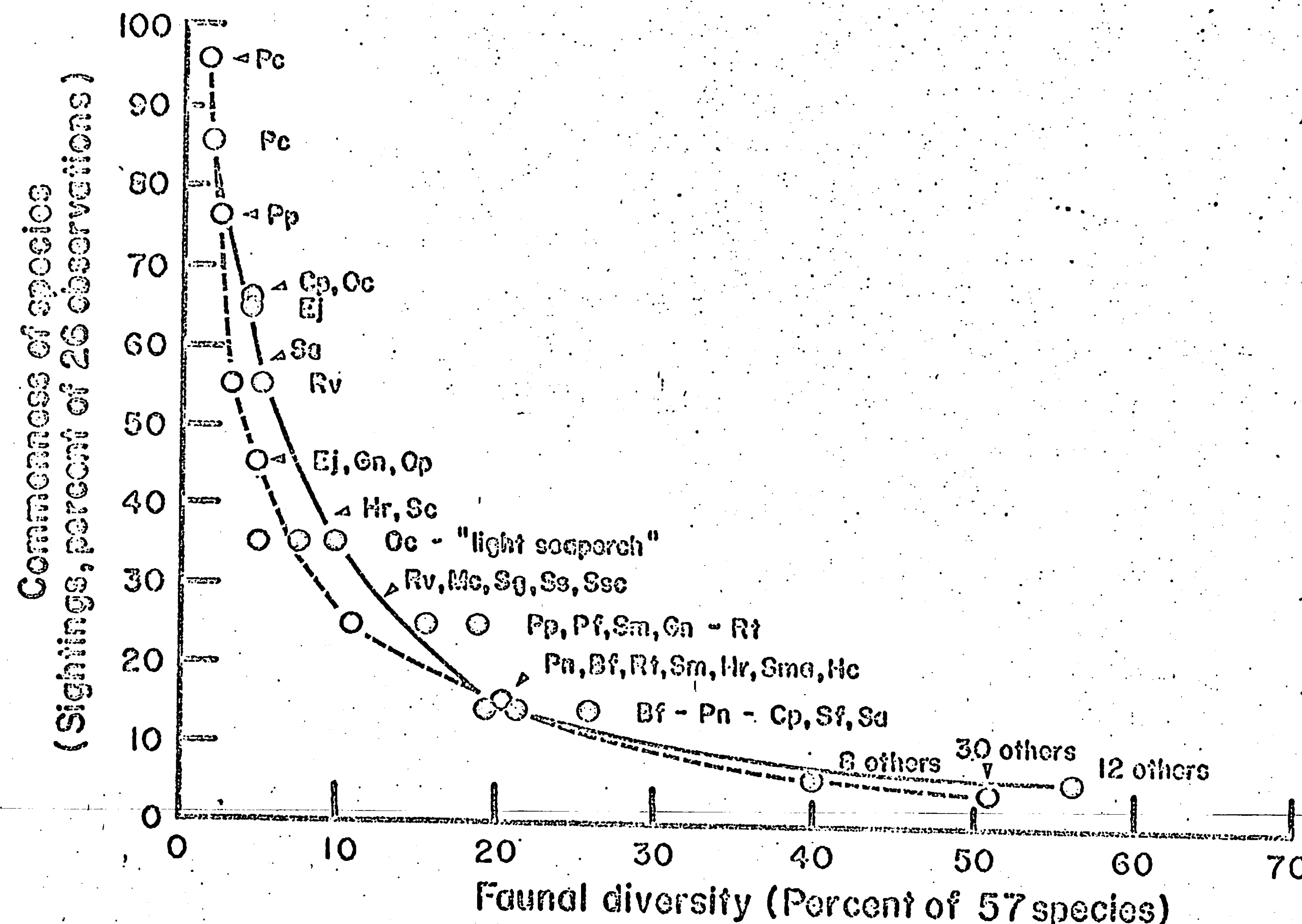
Commonness of species
(Sightings, percent of 26 observations)
100
90
80
70
60
50
40
30
20
10
0
Pc
Pc
Pp
Cp, Oc
Ej
Sa
Rv
Ej, Gn, Op
Hr, Sc
Oc - "light seaperch"
Rv, Mc, Sg, Ss, Ssc
Pp, Pf, Sm, Gn - Rt
Pn, Bf, Rt, Sm, Hr, Sma, Hc
Bf - Pn - Cp, Sf, Sa
8 others
30 others
12 others
0
10
20
30
40
50
60
70
Faunal diversity (Percent of 57 species)

FIGURE 1. Relative commonness of overt rocky-inshore and kelp-bed fishes, based on the visual sightings of Quast (1968b) (open circles with species indicated by arrows) and on 26 film strips from the present study (solid circles). Note the correspondence between Quast's hierarchical distribution (dashed line) and the present hierarchy of fish commonness (solid line), whose species (points) in the same percentile of commonness (vertical scale) are ordered from left to right between dashes. Species are designated as (in alphabetical order): Bf, kelp perch (*Brachyisteus frenatus*); Cp, blacksmith (*Chromis punctipinnis*); Ej, black perch (*Embiotoca jacksoni*); Gn, opaleye (*Girella nigricans*); Hc, rainbow seaperch (*Hypsurus caryi*); Hr, garibaldi (*Hypsypops rubicunda*); Mc, halfmoon (*Medialuna californiensis*); Oc, señorita (*Oxyjulis californica*); Op, convictfish (*Oxylebius pictus*); Pc, kelp bass (*Paralabrax clathratus*); Pf, white seaperch (*Phanerodon furcatus*); Pn, sand bass (*Paralabrax nebulifer*); Pp, California sheephead (*Pimelometopon pulchrum*); Rt, rubberlip seaperch (*Rhacochilus toxotes*); Rv, pileperch (*R. vacca*); Sa, kelp rockfish (*Sebastodes atrovirens*); Sc, gopher rockfish (*S. carnatus*); Sf, yellowtail rockfish (*S. flavidus*); Sg, California scorpionfish (*Scorpaena guttata*); Sm, blue rockfish (*Sebastodes mystinus*); Sma, cabazon (*Scorpaenichthys marmoratus*); Ss, olive rockfish (*Sebastodes serranoides*); Ssc, treefish (*S. serriceps*).

(variables) out of the vast number composing the total picture (the kelp-bed component of the local ecosystem). We only contend that 28 pieces provide more information than two or three.

The temporal factor (I) indicates serial change in the system between October 17 and November 21, 1969, obviously too short a period to show seasonal trends. Translating the array of loadings into working hypotheses, the standing crop of phytoplankton as measured by chlorophyll "a" apparently increases as proportionately more stations are made inshore where the kelp is less dense (Table I). After a period of dry Santa Ana winds, which warms the water, furthermore, the relative humidity increases (as the weather cools). And as winter comes, live anchovy bait becomes scarse so that a deep sport fishery for rockfishes (which bite on dead bait) replaces the preferred surface fishery for kelp bass, an inverse relationship also implied in a previous study (Ebeling et al., 1970).

TABLE I. FACTORS IN THE KELP-BED SYSTEM THAT GROUP SELECTED VARIABLES INTO CAUSAL ARRAYS. VARIABLES ARE ORDERED BY THEIR RELATIVE "IMPORTANCE" TO THE FACTORS AS INDICATED BY THEIR LOADINGS (NUMBERS AT RIGHT).

Factor I: Temporal (Sept. - Nov.)		Factor III: Depth	
Date (days from 10-17)	.89	Bottom depth	.84
Chlorophyll a	.91	Photogr. depth	.76
Kelp density	-.87	Black perch (Ej)	-.63
Relative humidity	.74	White perch (Pf)	-.61
Rockfish catch/angler	.71		
Kelp bass catch/angler	-.69		
Bottom temperature	.67		
Factor II: Bottom relief		**Factor IV: Abundance-visibility**	
Bottom type (increasing relief)	.90	Fish abundance	.79
Bottom invertebrate abundance	.93	Señorita (Oc)	.76
Total fish species (diversity)	.77	Kelp perch (Bf)	.71
Diversity of bottom algae	.72	Bait fish prevalence	.61
Blue rockfish (Fig. 1 - Sm)	.61	Kelp bass (Pc)	.60
Opaleye (Gn)	.59	Transect visibility	.58
California sheephead (Pp)	.57		

Variables not loading significantly on any factor

Rubberlip seaperch (Rt)
Pile perch (Rv)
Surge
Location relative to kelp bed

The bottom relief factor (II) indicates that rocky bottoms with high relief support greater diversities of fish, more invertebrates, and a greater variety of benthic algae. Certain fishes may prefer rocky bottoms to dense kelp forests.

Although the depth factor (III) appears incomplete at this stage, the abundance factor (IV) affirms that kelp bass eat smaller fish and appear most abundant and conspicuous when bait fish prevail. Also, either more fish of all kinds are in camera range when the water is clear or more fishes of the kelp beds are generally active in clear water. Note that the two most cryptic species, the senorita (Oc) and kelp perch (Bf) are most conspicuous in clear water.

The rubberlip seaperch, Rhacochilus toxotes, and its congener, R. vacca, seemed to range evenly throughout all habitats, so that they did not load significantly on any factor and did not correlate significantly with many other variables. Location of the dives relative to the position of the kelp beds and the amount of surge were also relatively unimportant links in the present limited system. Perhaps, in general, fish abundance per se depends less on giant kelp as on rocky reefs with dense cover and abundant invertebrate food (see factor II).

Discussion

Using film strips to record fish abundances has several operational advantages over the transect method of Quast (1968c), which requires underwater notations: (1) the observers (SCUBA divers) need not be experts on the local fauna, so that personnel can be interchanged as students enter and leave the program (all observations are recorded on film); (2) recurrent mistakes in fish identifications can be corrected by simply reviewing earlier films; (3) the observer is not distracted by underwater notations; and (4) permanent records of the environment accumulate for later specific analyses in retrospect, e.g., of clumping, habitat preference, behavior patterns, etc. The last is particularly important because factors may suggest interesting questions, previously not considered, that can be answered in retrospect.

The present method is at least as reliable as Quast's more tortuous technique. Only 26 film strips already show fish in about the same hierarchy of commonness (see Quast, 1968b). And the few observed differences reflect the more southerly fauna of San Diego. For example, the California sheephead (Pp of Fig. 1) and garibaldi (Hr) are higher in Quast's hierarchy because they prefer warmer water.

Even the present preliminary factor analysis looks very promising. Only two month's observations have already provided a meaningful organization of the limited system selected for this first trial. We already have hints that temporal events, bottom type, depth, and water clarity will be important pieces in our giant jig-saw puzzle that will depict the ecosystem. Some of the interactions, furthermore, substantiate relationships revealed in previous studies of trawled collections (Ebeling et al., 1970). The proposed expanded analysis of all 80 variables observed semi-weekly will undoubtedly generate a meaningful organization of the kelp-bed system and its interaction with oil pollution and the local sport fishery.

The preliminary analysis suggests interesting questions, the answers to which will provide more pieces to complete our puzzle. Many more questions will follow future analyses, where seasonal trends can be resolved. Are fishes dependent on the kelp per se, or more generally on cover provided by high relief bottom? Why does the kelp bass lead the frequency hierarchy? Is it really most abundant or is it just most conspicuous? If it is the most conspicuous of all kelp-bed fishes, why? Is it most conspicuous when bait fish prevail? Do fish in general prefer clear water or are they simply more discernible then? Do short term changes in water temperature affect the catch of sport fishes? Are some species more temperature independent than others? These and other questions generated by multivariate analysis can be investigated by direct observation in the field, review of previous films, or by controlled laboratory experiments in fish metabolism. Factor analysis puts us on the right track by revealing the most pertinent questions.

Proposed studies

We want to continue the present program of semi-weekly dives and filmstrip recording through two years, so that seasonal factors can be resolved among the 80 variables observed. This should resolve the main environmental gradients that partition the ecosystem into spatial and temporal communities and concourses; and the reactions of these ecological groups to climatic or artificial disturbances.

Occasional visual transects will be made concurrently with the film strips to see if there is a systematic difference ("correction factor") between what can be seen and what can be photographed underwater. The excellent correspondence between the two species frequency curves discussed above already indicates that such an extrapolation from film strips to in situ observations will be forthcoming. To do this, a third diver will accompany the cinematography pair and record sightings on an underwater tape recorder. Thereby, we may estimate the total fish biomass of the kelp beds by using Quast's (1968b, c) extrapolation from transect sightings and visual abundance estimates to direct estimates made by surrounding and poisoning whole beds, a difficult and expensive operation hopefully avoidable at Santa Barbara.

Finally, we plan to test several of the hypotheses generated by the multivariate analysis. Although we already have a partly equipped laboratory for metabolic studies, etc. we require funds to buy some new equipment, replace other components, restock supplies, and support an additional physiologically-oriented research assistant, who can also help with the environmental studies.

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TRACE METAL ANALYSIS OF OILY BEACH POLLUTANTS IN THE SANTA BARBARA CHANNEL

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PROGRESS REPORT

Work on this project began in mid-June, 1969. An earlier starting date was not possible due to the unavailability of a greduate student with the necessary prerequisite skills. The first six weeks were spent in obtaining the University of California diving certification (60-foot depth) and in preliminary exploration of the offshore natural oil seeps in the vicinity of Coal Oil Point.

At the earliest practicable date (late July, 1969), collection of oily deposits from coastal beaches was initiated. Beaches selected for the sample collection range from Jalama County Beach just north of Point Conception to Emma Wood State Beach just north of Ventura. In all, nine beach locations are visited on a monthly basis and approximately ten samples of beach tar are collected from each sampling station. To date, over 500 individual samples of beach tar have been collected and await analysis for their nickel and vanadium content.

Concurrent with the beach sampling program, efforts were undertaken to obtain samples of natural oil seepage directly from ocean bottom locations. Preliminary activity was directed to Coal Oil Point since it is the most active seep region in the Santa Barbara Channel. Several dives over a two-month period resulted in the collection of about twenty ocean bottom samples of natural seep material.

Bottom sampling at locations other than Coal Oil Point has not been very productive. While areas of natural seepage have been reported all along the coastline of Santa Barbara County, the current activity of these seeps is apparently so low that their locations cannot be found. The main areas involved in this exploration have been Carpinteria and Point Conception. Upon return of more favorable weather conditions, efforts in this direction will be resumed.

In addition to fieldwork, substantial time has also been devoted to the analytical phase of the study. Because of problems with equipment vendors, installation of the atomic absorption spectrophotometer was not completed until late August, 1969. During this interim, a literature survey was made and several research labs in the Los Angeles area were consulted regarding analytical methods.

Not unexpectedly, several problems were encountered in the trace metal analytical procedure. Because of the large number of samples to be processed, the more conventional method of ashing followed by aqueous dissolution was bypassed in favor of direct solution in an organic solvent. Precedent for this operation, however, was based on the analysis of oils rather than the viscous, tarry matter encountered in this study. In particular, the problems that arose were associated with the selection of a suitable organic solvent, the selection of a suitable calibration procedure, and instrument drift as a result of carbonaceous buildup on the burner. These problems are now almost completely resolved and analysis of the many samples is expected to get underway shortly.

Projection for the successful completion of this study still remains high. The past six months effort, however, have put the program objectives in a different light. The original question posed in this investigation was "Which areas of natural seepage, along the sixty miles of affected coastline, are responsible for the major amount of pollutant tars found on Santa Barbara beaches?" The approach being used to answer this question is based on the assumption that oily material from each of the area's active seeps can be characterized or fingerprinted by trace metal analysis. This approach, however, presupposes that ocean bottom samples from several locations can be collected. This supposition now seems unlikely in view of the difficulty in locating natural seepage at areas other than Coal Oil Point.

At present, it appears likely that results will be based primarily on the analysis of beach samples. A substantial portion of these samples are expected to be positively linked to the seepage at Coal Oil Point. Others, however, could well show a trace metal content substantially different than those originating at Coal Oil Point. If this proves to be the case, it would then be safe to conclude that other regions of seepage, while of unknown location, are also contributing to beach pollution in the Santa Barbara Channel.

EFFECTS AND IMPLICATIONS OF PETROLEUM POLLUTANTS ON THE RESOURCES OF THE SANTA BARBARA CHANNEL PHASE I - INFORMATION ANALYSIS AND PLANNING

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PROGRESS REPORT

Shortly after the proposal to conduct this study was completed, a massive oil pollution incident occurred in the Santa Barbara Channel. One of the effects of this incident has been to change national policies and priorities with regard to pollution of the sea by oil. An important aspect of this changing attitude has been the dramatic increase in research and development on the causes, prevention, and cleanup from oil spills. Unlike the almost static condition that existed prior to the Santa Barbara oil spill, new knowledge is being generated at a prolific rate.

As stated in the original proposal for this study:

> "The objective...is to gather pertinent background information ...and indicate those areas where new research must be undertaken to fill in the necessary gaps. The results...will be used to determine the long-range goals and establish priorities for future studies of pollution in the Santa Barbara Channel."

While this was a reasonable objective at the time the proposal was written, it has taken on a new light in view of the sudden flurry of research activity. In other words, a critical assessment of future research needs would be a presumptuous undertaking without some feedback from the large number of current studies.

For this reason, the major tasks proposed in the original study have been held in abeyance. Past and current efforts have been directed toward preparing a bibliography of pertinent literature and toward the difficult task of keeping up-to-date on the activities of various government agencies and public and private research organizations. Unfortunately, a considerable amount of information is tied up because of the current litigation between the Federal Government, the oil industry, and the Santa Barbara community. It is hoped, however, that, within the next six months, results from the initial complement of research programs generated by the Santa Barbara oil spill will become available. At that time, work can proceed as originally planned.

To date, less than one-third of the funds granted for this study have been spent. It is expected that this condition will also exist at the May 31 termination date. As intimated above, the balance of the available funds will be used during the automatic six-month extension. It is also possible that some budgetary adjustments, in the form of reallocation of existing funds, will be necessary to complete the study. This possibility, however, will depend on situations and factors that are presently unknown.

CULTURE, BEHAVIOR AND PHYSIOLOGY OF THE CALIFORNIA SPINY LOBSTER, PANULIRUS INTERRUPTUS

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PROGRESS REPORT
(June 1, 1969 to January 1, 1970)

Behavioral and Developmental Studies

Culture facilities and larval culture. During the *Panulirus* breeding season, approximately June to August, 1969, berried females were brought into the laboratory and held until spawning under one of two conditions: in flowing, non-recirculated seawater or in a large recirculated system. It was initially thought that the closed system would facilitate harvesting hatched larvae, but in actuality this proved to be no great problem in the flow-through system. The later will be used exclusively during the present season since it requires less attention and seems to provide more viable larvae than the closed system.

Upon hatching, larvae were collected at a light and transferred into one of two systems. The first provided for mass culture in 4-gallon containers of recirculated sea-water. Optimal suspension of larvae was obtained by a water inlet arranged to produce a slow rotation of entire volume and by draining through a wide filter bed of oyster shell and charcoal at the bottom of each container. In the second system, small numbers of larvae were kept in 200 ml dishes and transferred daily.

In both systems, larvae were fed *Artemia nauplii*. Both culture methods yielded usefully large numbers of early stage larvae for experimentation but mortality was total by the 4th molt. Therefore, neither method will be used during the breeding season just commencing. Instead, the procedures used by the San Diego State College group will be used (see proposal for next year).

Experiments with larvae

Nutritional. In an effort to determine the possible significance of dissolved organic matter in larval nutrition uptake, experiments were conducted with C^{14}-glutamic acid. No specific uptake of significance was observed.

Behavioral. Photic orientation. Phyllosomes were examined for behavioral photic orientation. Light from a monochromator, adjusted to equal relative quanta by a thermopile method, was directed along a 10 inch tube. Photic responses were measured by determining the time required for larvae to move the length of the tube to the end nearest the light source. While there was some orientation in the red, green light was associated with most rapid orientation. The method is quite suitable for the determination of action spectra and its use will be continued.

Experiments with adults

Chemoreception. An extensive series of experiments has been completed in which the response spectrum of dactyl chemoreceptors has been determined for a series of amino acids. Receptor axons were identified by recording from small bundles of dactyl neurons while stimulating the dactyl with 0.5 M glycine. Examples of experimental data are shown in Fig. 1. In general, the results indicate an amino acid chemoreceptive spectrum similar to that which we have shown for *Cancer*.

Competition experiments have shown so far that there are at least two classes of amino acid receptors on the lobster dactyls. Thus, of the class of receptors detected by glycine screening, their adaptation to glycine leaves them still responsive to leucine or glutamate but adapted to valine.

Respiratory physiology. A variety of respirometers and other equipment for respiratory studies was constructed during this initial period and preliminary studies have been made on several of the topics considered in this part of the original application. We have found that adult *P. interruptus*, unlike the Maine Lobster (Thomas, 1954), is able to regulate its oxygen consumption rate down to a lower limiting oxygen concentration (about 2.5 ml O_2/l.). Dissections have been performed to determine the optimum locations for sensors and cannulae in the lobster circulatory system. Initial studies on blood flow and heart rate suggest that a 2 lb. lobster normally has a heart rate of about 50 beats/min. Now that most of the required equipment is here and ready to be used, rapid progress is anticipated in the next few months. However, due to initial delays in obtaining essential apparatus, it will probably not be possible to complete all of the work originally proposed.

The effect of pollutants. Our first effort in this regard is complete and consists of a questionnaire prepared by Mr. James Lindsey and distributed to 200 commercial lobster fishermen and 3000 sport fishermen in order to gain their collective impression of the status of the lobster fishery, since the oil spill. In summary, the commercial fishermen (53 responses) perceive a decline in the commercially harvestible population. That is, 33 maintained that their yield was diminishing, 15 were maintaining yields as before but with greater effort, while 5 were of the opinion that the yield per unit effort is increasing. The sport fishermen were more convinced of declining populations (1190 report decline, 198 report stability and 12 noted an increase in their catch).

STUDIES OF SEAWEED RESOURCE MANAGEMENT

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PROGRESS REPORT

Introduction

The report covers research carried out during the first eight months under the subject grant. Aided by the existing facilities at the UCSB Marine Laboratory and by the availability of a small research vessel, we have been able to make progress in four areas of research: (1) structure and function of seaweed germ cells, (2) substrate studies, (3) vegetative propagation of the agar weed, Gelidium robustum, and (4) economic studies.

Detailed reports on the work in each of these areas are given in the following sections.

Some instrument development has been required (1) to provide for water motion in our laboratory aquaria, and (2) to equip sea sites for field work. These items are reported in those sections on botanical research to which they apply.

Much effort has been devoted to coordinating our work in various areas and providing mutual support between individual projects. Weekly meetings of the research staff have been held to coordinate the work that is going on and to review plans for the future. This approach of a "unified program" will become more significant as various phases of the research mature and the broad outline of a seaweed management or cultivation program begins to appear.

Structure and Function of Seaweed Germ Cells

Ultrastructure and Cytochemistry

The fine structure of the eggs and tetraspores of Dictyota binghamiae and the zoospores of Macrocystis angustifolia has been studied with the electron microscope. In Dictyota, the eggs and tetraspores develop from stalk cells, which undergo marked structural changes in the nucleus and nuclear pores; the increased activity of the nucleus is indicated by the number of vesicles produced. Fig. 1 shows a stalk cell in the process of development; Fig. 2 shows a normal stalk cell; Fig. 3 shows details of pore structure in a developed cell.

The micrographs of Dictyota indicate the mechanism by which the eggs are released. In the young cell a cross-wall forms at the basal end; Fig. 4 shows an early stage of the new wall; Fig. 5 shows a slightly later stage with a substantial quantity of mucilage adjacent to the wall. Fig. 6 shows large granules in the vicinity of the new wall and it is suspected that their presence may be related to wall formation, although the cytochemistry of the granule is presently under investigation. The wall forms a barrier between the egg cell and the basal cell. Release is effected by separation of the wall into two layers. Fig. 7 shows a structure within the newly formed wall which is suspected to be the beginning of the separation process. The fully separated wall is shown by the two layers evident in Fig. 8.

Cytochemical studies using protein and carbohydrate localization tests have shown that both the eggs and tetraspores of Dictyota contain large amounts of protein and carbohydrate, especially in the granules. The mucilage layers of the sori contain both protein and carbohydrates and they stain to a much higher degree than the cytoplasm.

Macrocystis zoospores develop from a zoospore mother cell (Fig. 9). The number of spores produced by each mother cell is under investigation. The fine structure of the zoospore shows it has a large nucleus surrounded by a wide envelope. A single chloroplast, closely associated with the nucleus, is found in each spore (Fig. 10). The cytoplasm of the spores contains numerous mitochondria (Fig. 10), more than are found in other types of Macrocystis cells examined. The zoospore has two flagella at its basal end, each with a nine plus two microtubule structure (Fig. 11). This work on Macrocystis is currently being prepared for publication.

Growth and Germination of Reproductive Cells

A new instrument has been developed for producing water motion in a laboratory aquarium that simulates the scouring of wave surge over rocky substrates in the ocean. This instrument, called the OSCARS* III water broom, consists of (1) a tract-carriage-drive system and (2) a nozzle-pump system. A photograph of the water broom in position in an aquarium is shown in Figs. 12 and 13. In Fig. 12, the nozzle has been raised out of the water to show its two sheet-jets emerging at 45° each side of the vertical. In Fig. 13, the nozzle is submerged and directs its jets onto the surface of a substrate rock. (The jet is faintly outlined by bubbles in the flow.) When the water broom is in operation, the carriage moves back and forth on its track (left and right in the photographs) and the two sheet jets "sweep" the surface of a substrate placed on the rack as the nozzle passes over it. Pumps continuously recirculate water from the aquarium through the nozzle and back. The traverse rate may be varied from stationary to several feet per second; the cycling frequency is adjustable by changing the track length; the velocity of the water jets can be varied from zero to a maximum of 25 ft/sec; the width of each jet is fixed at 9" but the sheet thickness is changeable in steps from 0.005" to 0.045" (the jets in the photographs have sheet thickness of 0.015"); the distance of the nozzle from the substrate is adjustable and may be varied from rack to rack by changing rack height. Since the flow produced by a 2-dimensional jet impinging on a flat surface is well known, the OSCARS III water broom enables the experimentalist to generate a flow field over his substrate that has a known velocity distribution and is controllable within the limits of the instrument. The water broom will be used to investigate the effects of water motion on the germination and growth of algal spores. At present, it is being calibrated.

*OSCARS: Ocean Surge and Current Algal Research Simulator

Substrate Studies

Field Experiments and Laboratory Growth

Mats of small macroscopic algae (turf) from Pt. Dume, Coches Prietos, and Naples Reef have been collected and identified. Five turf species transplanted to the laboratory have continued to grow over a period of 4 months under conditions of low light (70 - 300 foot-candles) and temperatures of 15 - 19°C. A grid of marked bricks has been put out over Naples Reef. Algal growth on these bricks is being followed to determine if turf species represent a stage in succession to a community of larger algae. The brick studies are being carried out in conjunction with scraping-recolonization experiments at Coches Prietos.

Collections so far indicate that turf varies greatly in species composition. The most prevalent species include _Pterosiphonia_, _Spermothamnion_, _Chondria_, and _Murrayellopsis_. Substrate, current light, temperature, and associated biota have been measured and classified in areas where turf has been collected, but not enough data have yet been accumulated to significantly characterize the environment of various turf communities. Qualitative observations indicate that large macrophytes such as _Eisenia_, _Macrocystis_, _Gelidium_, and _Gigartina_ seem to favor substrate edges for attachment and growth, while turf is generally found on level surfaces. Various substrate types are being used to test this observation.

Associated Laboratory and Field Equipment

A surge simulator, the OSCARS IV, has been developed for use in the greenhouse. This machine develops a back and forth surge motion in large culture tanks. The motion is accomplished by dividing the tank into three channels. Paddles are placed in the two outer channels and are driven back and forth by a frame connected to a crank. The water displaced by the paddles flows through the inner channel containing experimental plants (see Figures 14 and 15). A maximum velocity of 2.6 ft/sec has been developed with the apparatus. This is within the range of velocities which have been found in the field at Coches Prietos and Naples Reef. To measure water velocities in the field and in the surge simulator, a hand-held current meter, consisting of a sphere attached to a line and a scale for measuring the angular deflection of the sphere, has been developed and used successfully (see Figs. 16 and 17). With a ping pong ball as an indicator, currents from 1 to 3 ft/sec have been measured at depths up to 20 ft. A family of similar current measuring devices for use under a wider variety of laboratory and field conditions is being developed based on the original model.

Vegetative Studies

Gelidium Growth

Various facets of vegetative growth are being studied, primarily dealing with _Gelidium robustum_. Re-growth of plants harvested in the sea, germination and growth of sporelings, and the growth of vegetative fragments has been studied.

Preliminary experiments indicate that _G. robustum_ tetraspores germinate and develop (Fig. 18) in a manner similar to that reported for _G. pusillum_. Initial sporeling growth appears to be slow, 3 cells with rhizoids in 12 days, and water motion is being investigated as a means of enhancing growth over that obtained in still water.

The growth rate of G. robustum vegetative fragments varies with water motion, the maximum rate being 4.8 mm/week for main axis elongation at a current velocity of 0.3 m/sec in a whirl-pool water tunnel, the OSCARS II (a circular culture container in which the seawater rotates relative to the fixed plants). The growth rate at 0.3 m/sec was significantly (5% level with analysis of variance) greater than rates obtained for plants in still water cultures and at the relatively calm marine laboratory outplanting area (Fig. 19).

Diatom Control

A significant epiphytic growth of diatoms appears on G. robustum grown in the laboratory. The rate of diatom growth varies with water velocity, first increasing to a maximum at a water velocity of 0.4 ft/sec and then decreasing sharply by a water velocity of 4.0 ft/sec (Figs. 20 and 21). Since the water velocities currently in use in the laboratory fall within the range of increasing diatom growth rate, water motion by itself does not appear to be a promising method of controlling diatoms. Other means of diatom control are being tried, such as the use of germanium dioxide.

The recovery of harvested G. robustum in the sea appears to be slow. The average regrowth rate measured at Point Dume, Los Angeles County, was 1.1 mm/week for the central axes that had regenerated (54% of the axes cut regenerated) during the period from August 24 to October 19. Membrinopora (a bryozoan) growth over the cut harvested branches may have been an important factor influencing the regeneration. Growth rates, agar content and properties, epiphyte growth and regeneration rates in the sea are presently being studied for seasonal and geographic variation. Knowledge of these parameters should be useful in determining resource management procedures.

Light

Experiments on vegetative growth require that the aquaria in the laboratory are illuminated with artificial light sources, filters, screens, etc., in such a way that the spectral distribution and intensity of the light at the plants have certain specified values. In order to facilitate the operation, a brief study has been made of the relation between photometric and radiometric units and of the procedure for converting the lightmeter reading (in foot candles, say) into incident radiant energy (in watts/cm^2, say). An equation has been derived for converting the meter reading to incident radiant energy in terms of quadratures (simple definite integrals) involving the spectral luminosity of the light source, the spectral luminosity of the light for which the meter is calibrated, the relative spectral sensitivty of the meter, and the standard luminosity curve. A report is in preparation.

Economic Studies

Research on the economics of the seaweed industry has been and will continue to be concentrated in the following five areas:

General Survey of the Current Status of the Seaweed Industry

Data have been accumulated on available raw materials (species), potential outputs, and the structure of markets for seaweed products. A concerted effort has been made to obtain statistical series on prices and quantities sold for the major seaweed species over the past several decades. Evidence has been obtained from (1) published literature; (2) the records of operating firms; (3) general markets, such as the International Seaweed Exchange; and (4) comments and private communications from various academic and industry experts. Most seaweed is sold in incidental "spot" markets or harvested by vertically integrated firms whose records are closed.

Data on the total harvest of Macrocystis from California waters from 1916 to 1968 have been provided by the California Department of Fish and Game. These figures, combined with data on the Mexican kelp harvest exported to California for the years 1966-68 give a good picture of the utilization of Macrocystis on the Pacific Coast. The following table gives the California harvest, the Mexican harvest, and the total harvest in tons of wet Macrocystis.

	U. S.	Mexico	Total
1966	119,464	23,141	142,604
1967	131,495	20,755	152,250
1968	134,853	28,478	163,331
Average	128,600	24,125	152,728

The value of the kelp harvest has been difficult to determine because there is no open market for Macrocystis. However, Productos del Pacifico, the Mexican firm which harvests on the Pacific Coast of Baja California and sells its entire harvest to Kelco, Inc. of San Diego, has stated that the price it receives ranges from $6.50 to $8.50 per ton of wet kelp. Taking these figures as upper and lower bounds on the value of kelp, the total value of the average annual harvest of Macrocystis on the Pacific Coast may be said to fall between $992,335.00 and $1,298,193.00.

Markets, where they exist, are small and scattered, making it difficult to draw inferences concerning "average" or "competitive" levels of price. We shall continue to collect and refine all available data concerning other seaweed markets, but in view of present uncertainties, we must conclude that the economic outlook for a capital-intensive mariculture is both clouded and risky. Where the estimated costs of production seem favorable in relation to presently known or inferred market prices, certain species have been proposed as tentative production alternatives. The dynamic character of markets for food and drug extracts from plants of the sea is obvious, however, and we shall continue to explore hypothetical as well as currently exploited markets in determining the optimum present and prospective investments in mariculture.

Technology of the Seaweed Industry

Harvesting methods for most seaweed have remained surprisingly static over time. A number of mechanical harvesters, based on a rather rudimentary design, have been used in the harvest of Macrocystis by both U. S. and foreign firms. A newer technique, involving an air-lift mechanism, has been described in the technical literature, and newer versions of the mechanical harvester are being tested in Maine (for the harvest of Chondrus crispus) and in Southern California (for Gelidium robustum). Various degrees of intervention in the natural growth patterns of seaweed have been attempted as a means of increasing the available supply. American firms, such as Marine Colloids, have established pilot seaweed farms. Only in Japan have such techniques been brought to maturity. We have started to collect all available engineering and production data on newer techniques of harvesting and processing seaweed and will continue to do so.

The Nature of Demands for Seaweed Products

Current prices give only limited information to the firm contemplating entry to an industry. In the case of seaweed, this is particularly true for most markets have been only superficially explored and several are totally hypothetical.. Two fundamental questions must be answered in this connection: what is the elasticity of demand for those seaweeds presently being marketed? And what is the likelihood of developing new (presently untapped) markets for seaweed products? In respect to the first question, we are attempting to assess the impact that the entry of new producers will have upon the prices received by all in markets where current price data are available. Here the size of the present market in relation to the entering firm's optimum rate of output is of critical importance. Since long run elasticities of demand are judged, in the case of seaweed, to be considerably higher than short run elasticities, the "staying power" of the entering firm--its ability to withstand initial losses--becomes highly significant. In respect to the second question, we propose to investigate the possibility that seaweed could become a major raw material in food and drug industries of the future.

Public Policy Implications of Mariculture

Our consideration of public policy toward mariculture has been limited to these questions: (1) To the extent that seaweed is a common property resource, what is the socially optimal rate and method of its exploitation? (2) Furthermore, from the point of view of optimal resource allocation, how should public authorities set the prices paid for access to this resource? (3) To what extent does the harvesting of seaweed contribute to (or alleviate) coastal pollution? This question must be considered in the context of cost-benefit analysis. While these questions are not major concerns of our present research, directed as it is to the assessment of the economic potential of self-contained mariculture, we are devoting additional effort to providing answers in this area as well.

Establishing a Rank Ordering of "Most Favorable" Seaweed Cultivation Industries for the Southern California Coastal Area

This is the single most important purpose of our economic studies and represents a synthesis of all the data accumulated under the section headings given above. The development in the primary portions of the project study of a living "production function" for various species from basic biological and ecological data becomes, for us, the basic raw material input in an economic production function from which we derive a series of estimated costs and outputs. From our market data, we then derive estimates of gross annual revenues allowing both for elasticities of demand and for some market innovation. Comparison of net revenues with original investment costs yields a figure for the rate of return on investment, an index of the profitability of each potential species.

To date our rankings are tenuous. Our first choice, Gelidium robustum, has a high current market value but its apparently slow growth rate may create an economic barrier. Ranked as second is Gracilaria verrucosa, also an agar weed, which though lower priced in current markets may have advantages in terms of rate of growth, ease of establishment, and growth under conditions which facilitate intervention and harvesting (as compared to Gelidium). Ranked as third is Gigartina which, like Gracilaria, may show rapid growth and easy colonization in pilot farms. Its market value is lower than the first two species mentioned, however, and it must therefore be considered a less promising candidate for full-scale production at the present time. We stress that these conclusions are tentative ones.

INVESTIGATION OF THE SEISMICITY AND EARTHQUAKE HAZARDS OF THE SANTA BARBARA CHANNEL AREA

Arthur G. Sylvester ✓

Assistant Professor of Geology

PROGRESS REPORT

Introduction

The Oil Spill

The massive oil spill in the Santa Barbara Channel during 1969 caused considerable premature attention to be focused upon our study, because several politicians argued that earthquakes constitute a major threat to offshore oil well drilling platforms.

The opportunity to obtain factual data regarding the seismicity and earthquake hazards of the channel was realized in June 1969 when this investigation was funded.

The oil spill has had an unexpected and adverse effect upon the seismological part of the investigation, however, as described below, which may not be possible to resolve within the duration of the grant.

Personnel Changes

We have had to alter our plan of investigation somewhat, because of several personnel changes. Graduate student, Ron Teissere, has taken over the strain study of J. D. Rietman who has left UCSB as of 1 January 1970. Teissere will do the work under the supervision of A. G. Sylvester, R. O. Burford, and J. H. Howard.

Several UCSB graduate students have become interested in our investigation, and we are directing their studies of certain selected problems as far as funds permit.

Progress and Current Status

Geological Studies

Our geological studies of the locations of faults and their histories of movement was complemented unexpectedly by publication of two studies by other investigators:

1) Geologic framework of the Santa Barbara Channel Region by J. G. Vedder, H. C. Wagner, and J. E. Schoellhamer (USGS Prof. Paper 679-A)

2) Geology of the Northern Channel Islands by D. W. Weaver and others (AAPG-SEPM Spec. Pub.)

Each of these publications contains much geologic information which will save us considerable time and effort. We shall continue to concentrate our efforts on documenting geometries and histories of certain large mainland faults which have submarine extensions on the assumption that the subaerial and submarine parts of the faults will be reasonably similar.

To date we have nearly completed a regional compilation of the geology from other sources. Next we intend to do a comprehensive study of the aerial photographs, looking for evidence of recent displacements along lines of known or suspected faults, and then we shall conduct field mapping in selected critical areas.

Study of Recent Crustal Strain

After long red-tape type delays, we have obtained the surveying instruments required to do the short-distance surveying aspect of the study. In the meantime we have located several likely faults which may be moving by creep, and we are in the process of putting survey networks across them.

The attempt to tie the Channel Islands to the mainland by long distance surveying with a laser geodolite was done in October. The attempt was frustrated by mechanical difficulties and by an unexpected shortage of funds (other agency funds, not NSF), so that this aspect of the study has had to be postponed indefinitely.

Seismological Studies

One of the most critical aspects of the entire investigation is the determination of the deep crustal velocity profile in the area so that earthquakes may be located more precisely. This requires a series of underwater calibration explosions.

Because of the oil spill, we have found strong opposition to our plans to fire the shots. Moreover, we have been denied the technical and advisory assistance to do the job in a careful, systematic way. Thus, we have been seeking alternate ways of locating and monitoring microseismic activity in the channel. To this end, Smith has been developing a sea-bottom seismometer which would telemeter data directly to UCSB or Caltech from the epicentral areas in the channel.

Another indirect effect which the oil spill has had upon our study as conceived and proposed initially, is that another agency has established a network of seven seismographs around the channel which is capable of doing a more complete method of recording and locating earthquakes in the channel than we had hoped or intended to do ourselves. Thus we have had to revise the scope and objectives of our seismological studies so that we do not duplicate unnecessarily those efforts of the other agency. We have argued, for example, that calibration explosions are needed in the channel, but not so much by us any longer as by the other agency which also has had great experience in doing calibration explosions. Therefore, we consider that we can use funds previously committed for the calibration explosion 1) in supporting parts of our study which are proving to be very promising but the costs of which we underestimated in our first budget; 2) in developing alternatives to the calibration explosions which will serve our purposes; and 3) in supporting a new and extremely significant study which has come to light as a result of our studies and of the oil spill: the role of fluid pressure variations in the prediction and prevention of earthquakes.

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ECONOMIC EVALUATION OF OCEAN MINERAL RESOURCES DEVELOPMENT AND RELATED PUBLIC POLICY ISSUES

Walter J. Mead
Professor of Economics

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Associate Professor of Economics

PROGRESS REPORT

The objectives for our two-year study under the initial Sea Grant proposal were stated as follows: "(1) a comprehensive private cost-output analysis for several promising minerals; (2) estimates of the discounted private rates of return for the same minerals; (3) a comprehensive study of external costs and benefits; and (4) further exploration of alternative public policies relative to marine mineral development."

Since June 1, 1969 we have published one paper evaluating the profitability of marine phosphorite recovery operations off the coast of Southern California.[1] After estimating the cost ranges for dredging, beneficiating, transporting, off-loading, and land transporting phosphate rock to a processing facility, and then appraising other non-quantifiable factors, we concluded that "development of marine phosphorite off the California coast is not presently economically feasible and may not be so within the present century." This paper fits under our first and second objectives.

Under the third objective we presented a paper before the UCSB Marine Science Institute "Symposium" on January 12, 1970 concerned with external costs and benefits of marine mineral development. A refined version of this paper will be presented before the Offshore Technology Conference in Houston, Texas, April 23, 1970. This paper will be published in the Proceedings.[2] It points out that "if a free enterprise system is to produce an optimum allocation of resources..., external costs and benefits must be internalized and unjustified interferences with the system of competitively determined market prices should be eliminated. Where uncompensated externalities exist and where market prices fail to reflect competitive forces, private enterprise in making critical investment decisions wastes resources either in over or under development. One means whereby net external costs may be internalized is to levy a tax on the offending industry equal to the reduction in total benefit resulting from the total operation. In instances where net external benefits accrue we have a *prima facie* case for a public subsidy equal to the amount of the net benefit accruing to society."

Under the fourth objective, Professor Mead presented a paper before the Rocky Mountain Petroleum Economics Institute. This paper analyzed alternative public policies for leasing oil and gas resources owned by the Federal Government.[3]

Also under the fourth objective we have presented testimony and public lectures. Professor Mead testified before the California Legislature, Assembly Revenue and Taxation Committee, on the subject of the mineral depletion allowance as a subsidy. Professor Mead also gave a series of public lectures in January, 1970 at the University of Alaska (both Fairbanks and Anchorage), and before the Alaska State Legislature in Juneau, Alaska. These lectures were concerned with mineral leasing policy alternatives under consideration by the state of Alaska. In addition, there were radio and television appearances in Alaska. Professor Mead served on a panel at the June, 1969 annual meeting of the Marine Technology Society in Miami, Florida, discussing external costs and benefits associated with marine mineral development.

We also have work in process, which is already committed for publication. Professor Mead will testify before the U. S. Senate Committee on Interior and Insular Affairs on March 11, 1970. This testimony will discuss the economic significance of marine minerals to the future growth of the U. S. economy, appropriate regimes for the governance of marine mining activity, security of investments, economic justification for mineral development subsidies, and leasing policy alternatives. Professor Sorensen will present a paper before the annual meeting of the Marine Technology Society in Washington, June 29, 1970 entitled, "Evaluation of Technological Spillovers--the Case of the Deep Sea Dredge." This paper will estimate a function describing the decline in cost of production from a radically new technology. Special attention will be given to the development of a dredge capable of recovering deep sea minerals at depths up to 18,000 feet.

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[1]"A New Economic Appraisal of Marine Phosphorite Deposits off the California Coast," Marine Technology Society, The Decade Ahead, 1970-1980, 1969.

[2]"The Principal External Costs and Benefits of Marine Mineral Recovery."

[3]"Federal Public Lands Leasing Policies," Quarterly of the Colorado School of Mines, Vol. 64, October 1969, 181-214.

[4]"The Economics of Depletion Allowance," unpublished.

THE PRINCIPAL EXTERNAL COSTS AND BENEFITS OF MARINE MINERAL RECOVERY

by

Walter J. Mead and Philip E. Sorensen

Prepared for the Offshore Technology Conference

Houston, Texas
April 23, 1970

ABSTRACT

Investments in resource development by private enterprise will produce socially optimal results in only those instances where (1) monopoly power by private enterprise and unjustified interference with the market mechanism by government are absent, and (2) external (spillover) benefits and costs are absent. Government interference in order to raise the price of oil has caused a significant divergence between private and social benefits such that over-investment in oil exploration and development has resulted in serious resource misallocation. For marine minerals requiring major technological innovations in deep sea dredges as a prerequisite to development, the technological external benefits appear to be sufficiently large to constitute a *prima facie* case for a public subsidy. However, the amount of such a justified subsidy still does not appear sufficient to render deep sea manganese recovery profitable in the foreseeable future. On the other hand, there are external costs due to marine mineral recovery. These spillover costs are particularly evident in near-shore oil recovery. Efficient resource allocation within a free enterprise system requires that all externalities be internalized so that they enter into the profitability calculations of those economic units affecting the development of natural resources.

References and illustrations at end of paper.

INTRODUCTION

Decentralized decision making is an identifying characteristic of a pure free enterprise economy. Decisions regarding which resources to develop, when, how, and by whom, are made by individual business units rather than by government. Planning is provided by a relatively free price system where business units are motivated by pursuit of private profit. This system can be shown, in terms of a theoretical model, to produce optimum resource allocation and efficiency where prices are determined by effective competition, and where there are no externalities.

The purpose of this paper is to explore the effectiveness of private enterprise decision making processes regarding marine resource development. The paper is divided into three parts. First, we will identify the private decision making process. Second, the important externalities problem will be defined and introduced as a distorting influence for private decision making. Third, the principal external costs and benefits of marine mineral recovery will be identified, and the concept and method of calculating a social rate of return will be set forth.

PRIVATE DECISION MAKING IN RESOURCE DEVELOPMENT

The guiding motive for business in resource development, as in other areas, is pursuit of private profit. To the extent that the investment decision making process is rational, private rates of return for prospective investments are calculated. This involves estimation of required investments, estimation of the flow of gross revenues over time, and estimation of corresponding operating costs through the life of projects. This calculation is illustrated in Figure 1. In year 1 an investment outlay is shown without corresponding gross income. In year 2 relatively heavy investment and initial operating costs are shown corresponding with relatively low gross income. As income builds up in years 3 and 4, annual costs and revenues are reduced to a steady state condition showing annual revenues in excess of annual costs and a corresponding annual operating profit. Operations will continue as long as operating revenues exceed operating costs. When operating revenues become equal to or less than operating costs the operation will cease.

Given estimates of the time stream of investment, gross income, and operating costs, an appropriate discount rate is used to discount all revenues and costs to the present to arrive at discounted present values. If the discounted present value of the revenue stream is in excess of the discounted present value of the costs stream including the required investment, then the investment has a "go signal" for private enterprise. If the investment in question is exploitation of a marine mineral such as oil, and that mineral is subject to leasing from the government, then an enterpriser may bid a bonus amount up to the excess of the discounted present value of revenue over costs. His discount rate permits him to earn his required profit. Economic theory can demonstrate that if prices of all input and output items are determined by reasonably effective competitive processes, lacking both private monopoly and government interference with the price mechanism, and if there are no externalities, then this private decision making process will produce an optimum allocation of resources and a highest possible standard of living for an economy.

THE EXTERNALITIES PROBLEM

The theoretical discussions of the externality (also called "spillover") problem has been confused by the presence of several kinds of external economies and diseconomies. For the purposes of this paper, we are concerned with externalities defined as follows: Real costs borne by or real benefits received by economic units other than the production unit causing them. An example will provide meaning to this definition. Air pollution is normally an external cost because the cost of air pollution is borne by society rather than by the firm or other economic unit which causes the pollution. The problem of external costs and benefits is illustrated in Figure 2. As a private enterpriser estimates his costs and revenues he calculates only those private costs which he must bear and private revenues which he collects. From society's point of view however, costs and benefits may not perfectly overlap those of the firm. For example, if labor, machinery and power costs are determined under competitive conditions, use of these factors are real costs to both the firm and to society; the firm must pay for their use and society give up their use in some alternative production process. Figure 2 also illustrates that there may be some private costs which are not costs to society. One illustration is the cost of royalty payments from the firm to the government. This item is a transfer payment. It is a real cost to the firm but not to society. On the other hand, there are social costs, best illustrated by pollution, which society bears and which the firm may not be required to pay. Similarly the revenue calculation normally involves a large area of overlap. Where the prices of the product produced are determined by effective competition, and where government interference in the price system is not present, the value of production is both a private and a social benefit. However, some revenues may be external to the firm and accrue to society, but not to the firm. As an illustration to be developed in more detail later, some technological innovation may produce substantial benefits to subsequent producers and society in general, and may not be captured by the initial innovator. On the other hand, some private revenues may not accrue to society. Where monopoly power exists, or where the power of government is used to raise prices above the free market level, some of the revenues accruing to the firm are private but not social benefits.

In 1776 Adam Smith advanced the concept of the "invisible hand," which alleged that pursuit of private profit corresponds precisely with pursuit of the public good. Smith wrote as follows, "As every individual ...endeavors as much as he can both to employ his capital in the support of domestic industry, and so...that its produce may be of the greatest value; every individual necessarily labors to render the annual revenue of the society as great as he can. He generally, indeed, neither intends to promote the public interest, nor knows how much he is promoting it.... He intends only his own security; and by directing that industry in such a manner as its produce may be of greatest value, he intends only his own gain, and he is in this, as in many other cases, led by an invisible hand to promote an end which is no part of his intention."[1] Thus Smith totally ignored the possibility of spillover costs and benefits, and instead asserted a happy harmony between private and social interests.

A group of contempory economists known generally as the "Chicago School" continues the Smith tradition by utilizing any one or a combination of three positions: (1) Some assert that externalities are unimportant.[2] (2) In the absence of government regulation of any kind, and given a smoothly working price system, the free market may make its own adjustment for externalities.[3] (3) The cost of government intervention to correct for externalities may be greater than the cost of no correction.[4]

The concensus of economists appears to be that in those instances where net external economies are significant, resource allocation can be improved if external costs are levied on the responsible firm in the form of a special tax, and that where net external benefits are large, there is a rational basis for a public subsidy payable to the responsible firm.[5] Scitovsky holds that "external economies are a cause for divergence between private profit and social benefit and thus for the failure of perfect competition to lead to an optimal situation."[6] In his classic analysis of externalities, Coase concluded that the proper method to account for externalities is to consider the total effect, acknowledging that the externality situation involves a reciprocal relationship. This relationship may be illustrated in the marine environment. If a marine resource developer pollutes the water, beach or air, he thereby inflicts harm on society and not upon himself. If society prevents the developer from polluting, then society inflicts harm upon the developer. Either alternative may reduce gross national product. By following the Coase advice to have regard for the total effect, one sets up the problem in such a way that the external effects are encompassed in the decision-making structure. By this process, the net external costs and benefits accrue to the firm responsible, giving rise to the phrase

Where externalities are significant, optimum resource allocation may require calculation of a social rate of return for a resource development project, and the estimated social rate of return will be different from the private rate. In this section we will identify the principal external costs and benefits of marine resource recovery. Particular attention will be given to investments in oil production. This is appropriate since oil production from the marine environment is of greater gross value than all other marine mineral recovery combined from this environment.

Social benefits will be considered first. The principal social benefit is production of the mineral which is recovered. In the absence of monopoly power or government interference with the pricing mechanism, social benefit corresponds precisely with private benefit and the social benefit is measured by the gross value of mineral production. In the case of petroleum, however, there is massive government interference with the pricing mechanism on behalf of the segment of the oil industry which owns, or has existing investments in, crude reserves and oil production. The price of domestic crude delivered to East Coast markets prior to the 1969 price increase has been estimated at \$3.25 per barrel. However, it is also estimated that crude oil could be purchased in middle eastern markets, transported to the United States, and sold for \$2.00 per barrel.[7] Assuming an elastic oil supply at \$2.00 per barrel, it follows that the opportunity costs, and therefore the social value of oil, is \$2.00 per barrel, rather than \$3.25. A private firm in estimating its private rate of return from a given oil venture will quite naturally use current and anticipated future market prices. However, more than one-third of this market value is not real value to society but rather represents a transfer from the consumer to the owner of crude reserves.

There are two important market interferences producing the artificially high price. (1) The effect of market demand prorationing is to restrict output and thereby gain a higher price for the producer. The mechanism is illustrated in Figure 3. Hypothetical supply and demand curves for oil are shown. The equilibrium price and quantity is shown to be P_1 and Q_1. Those who own crude reserves would prefer a higher price for their product to a lower price. Utilizing the power of

Federal and State Governments, some producers are required to produce only a specified percent of the MER (the maximum efficient rate of production) and by restricting output from Q_1 to Q_2 a higher price, P_2, is generated by the market. (2) The second device for raising the price of oil follows from the first. If domestic prices are raised above free market levels, then the domestic market must be insulated from foreign supplies. Hence import quotas were imposed in 1958. The mechanism whereby import quotas increase the price of oil is shown in Figure 4. The domestic demand for oil is satisfied by domestic supply plus net imports. In the absence of any restrictions on free trade, Figure 4 shows that at a price of $2.00 per barrel total supply would equal demand and the market would be in equilibrium. From the point of view of the owner of crude petroleum reserves a high price is preferable to a low price. Clearly, if some segment of the competitive supply can be restricted, the new equilibrium price will be higher than before. The effect of import quotas is to permit the domestic supply (S_D) to be augmented by restricted imports. The domestic supply plus permitted imports is shown as S_{D+I}. With restricted imports, the new market price is shown at $3.25 and Q_2 is the quantity that will be supplied and demanded.

An estimate of the social rate of return for any investment must be based on the social value of the output. If the best alternative source of oil available to the U.S. market is imports from abroad, and if this source is available at $2.00 per barrel, then this opportunity cost becomes the social value of oil production from domestic sources.[8] Thus, these two interferences with the free market mechanism produce a divergence between social and private rate of return estimates, and the effect from this factor alone is over-investment in high cost oil exploration and production.

A second adjustment to the stream of social benefits may become necessary due to technological externalities. This case may be of critical importance to deep sea marine minerals due to the need for a radically new dredging technology. Though technological spillover benefits are widely recognized as logical additions to other benefits included in the cost-benefit analysis of public investment projects, there is little agreement as to what spillover benefits should be counted and even less agreement concerning the methods by which these benefits should be measured. In general, a new technology provides external benefits in two ways: directly, by reducing the market price of goods or services sold by the innovating firm; and indirectly, by diffusion of new ideas or "know-how" to other firms or industries which is eventually transmitted into lower prices (or higher profits) for those firms or industires. In order for the first kind of benefit to be realized, the pioneering firm must be forced by the structure of the markets it faces to lower the price of its outputs. The second group of benefits will occur whenever patent protection is imperfect. The essence of technological spillovers is the inability of the innovating firm to capture the total benefits of its pioneering activity.

Studies of technological change in various industries illustrate the dramatic potential cost reduction involved in many new processes from the production of rayon to the manufacture of diesel engines and coal mining equipment.[9] As a single extraordinary example of technological improvement, one study of the computer industry indicates that from 1946 to 1967 for a given dollar expenditure the amount of computing power that can be purchased has almost doubled each year.[10] In general, innovating firms have been able to capture a large enough part of the social benefits flowing from technological improvements (either by means of patents or because of the "diffusion-lag" discussed below) to repay their original investments plus expected profit. The question is, would this likely be true for marine mining and in particular for the deep sea dredge? If so, no public subsidy for its design and construction is necessary or economically desirable.

The present outlook, however, confirmed by our recent study of the economic feasibility of ocean mining for manganese nodules, is that subsidies in excess of $100 million may be required to compensate a pioneering firm for its probable capital losses in entering this industry. The question then becomes whether the external benefits of ocean mining are equal or greater than this pioneering investment cost.

To answer this question, we may first estimate the possible reductions in market prices for the several minerals contained in manganese nodules and, by application of these reductions to total consumption in the U.S., calculate the annual cost savings to the public. This provides a measure of the "consumers' surplus" enjoyed as a RESULT OF ONE NEW TECHNOLOGY.

RESULT OF ONE NEW →
TECHNOLOGY
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Employing the model used in our previously cited study, world prices for manganese and nickel might be expected to decline in price by about 3% while cobalt might fall by about 27% as a result of the increased supplies of these minerals made possible through a single efficient ocean mining operation.[11] The cost savings (in the world market) resulting from these price reductions would total about $80 million annually, approximately half of these savings being realized in the United States (based upon current levels of consumption).

In general, a return of $40 million annually in cost savings for society on an original investment of $100 million would appear to be sufficiently large to make the argument for a public subsidy very strong. Two additional considerations must be added, however, and both operate negatively. First, these savings will not accrue immediately but only after a lapse of from ten to twenty years, thus the present discounted value of the annual savings is far below the gross value cited above. Then there remains the high level of risk attached both to the original investment and to markets for minerals generally in the 1980's and beyond. There is a possibility that the dredge will never operate commercially. And even if it does, technological developments in the processing of land-based minerals may by that time reduce the prices of the contained minerals below the variable cost of obtaining them from the ocean, in which case no ocean mining firm can survive without continuing annual subsidies.

If we assume a 50% risk of failure on one or both of these grounds, combined with the 10% discounting factor, the present value of direct benefits on account of cost reductions is reduced to between $50 and $75 million, still considerably below the required public subsidy.

It is necessary then to ask whether technological spillovers to other firms and industries, benefits which are independent of those calculated as direct savings from price reductions, are sufficient to raise the total benefits to the level of expected costs. These indirect spillover benefits are more difficult to identify and to measure but we can obtain some idea of their nature and value from two recent major studies of analogous spillovers from aerospace research. The most comprehensive and analytically satisfactory of these studies was done by the British Ministry of Technology in respect to aviation designs developed by private firms under contract to the Ministry. The External economies from government sponsored design research were estimated to be approximately 10% of the cost of producing the new ideas embodied in the designs.[12]

The second study was by the U. S. Department of Transportation as one of its comprehensive panel reports concerning the advisability of continued federal support[13] for the supersonic transport program. Among the principal areas of technology which would be advanced by the SST prototype program, according to the Report, were (1) aerodynamics, (2) advanced flight controls, (3) aircraft tires, (4) high temperature structures, (5) aircraft engines, (6) fuel tank sealants and (7) environmental control systems. Despite this seemingly impressive list of potential technological externalities, the Task Force concluded that claims for technological fallout from the SST program were generally unconvincing, that many of the technologies were refinements of older developments already available, and that others were unduly specialized. In summary, technological externalities were not to be counted as significant in determining federal policy toward the SST.

The conclusions reached in these studies are of value in interpreting the spillover benefits of the deep sea dredge. First, indirect spillovers from dredge research will not likely exceed those flowing from aircraft design research -- about 10% of the cost of producing the new ideas. And second, the federal government will not accept as evidence of technological spillover benefits anything less than a unique and necessary cause and effect linkage.

We must note that there are areas of technology which would be expected to benefit from a successful deep sea dredge construction program, including (1) hydraulic transmission systems; (2) high pressure pumps, linkages and valves; (3) high strength non-corrosive alloys; (4) underwater television and sensing devices; and possibly (5) underwater vehicles. But this group of technologies is more limited and specialized than that given for the SST program, and the latter group was rejected by a prestigious government panel as "generally unconvincing."

A major difficulty in evaluating the impact of technological externalities on other firms and industries is the time span separating the original research from its practical application. Various stages are involved in the process of technological innovation including original conception, abstract design, modeling in prototype, experimentation, re-design, full trial, original production modeling, commercial availability and eventual general adoption. It has been shown that the length of time required for several major innovations to spread from their origins in one company to their use by other firms within the same industry was about 10 years in the period since World War II.[14] This "diffusion-lag" has a dual significance for our present problem. First, any indirect technological spillover benefits are not likely to be realized until a decade or more after the original designs are completed and thus the present value of such spillovers is much reduced. And second, the fact of "diffusion lag" gives the pioneering firm an extra-legal (apart from patent) measure of protection for its design, allowing it to earn additional monopoly rents. Both of these considerations tend to reinforce the earlier arguments against public subsidy for the deep sea dredge.

Thus, direct cost savings on major minerals available from deep ocean mining might provide a significant external benefit stream in the decade or two following original research and development of a deep sea dredge. But these benefits are uncertain and long delayed. More uncertain still are the indirect benefits of the new technologies advanced by deep sea dredge research. Most of these benefits are extremely specialized and likely to remain of advantage only to the pioneering firm for an indefinite length of time following introduction of the new technologies.

In the foregoing we have been concerned with estimation of social benefits. We now consider social costs. Under normal conditions, most of the private costs incurred by the producer are also social costs. In the case of oil production, all of the private costs of exploration, development, lifting and transporting to market, are both private and social costs, where there are no monopoly elements in these factor costs. In addition, costs incurred by the producer in order to prevent environmental pollution, and clean-up costs where pollution occurs, are both private and social costs.

However, some of the costs which a producer must bear are not social costs. For example, assume that oil has been discovered on a given federal lease and that profitable production has taken place from this lease. As an oil field approaches its point of economic exhaustion the operator will consider abandoning production. He will abandon production when his additional revenue per barrel of oil recovered no longer exceeds his additional cost, including royalty payments. In the absence of royalty payments, production would be continued as long as the additional revenue per barrel exceeds the additional operating cost. Once a well is abandoned it will not be reopened until there is either a substantial reduction in production costs (including the cost of reestablishing the well) or a substantial increase in the price of oil; and it is quite probable that production will never be resumed. Thus, the present value of additional oil that might be recovered in the absence of a royalty is lost to society. The royalty charge at this point therefore does not reflect a real cost to society. It is nevertheless a real cost to the producer.

In addition to private costs, which are also social costs, there may be external social costs. The primary category of external social costs is environmental pollution. Regarding oil production from the marine environment, environmental pollution may take the form of (1) scenery pollution, (2) water pollution, and (3) beach pollution. Scenery pollution occurs for those people who have built homes overlooking the marine environment, or who admire the seascape as they walk or drive along the seashore. Some people are offended by the appearance of drilling rigs and platforms on the seascape and feel a personal loss of value therefrom.

If scenery, water and beach pollution involves real costs to society not borne by the developer, then optimum resource allocation requires that these social costs be incorporated in a total calculation of the social rate of return.[15] The methods available to estimate these costs due to environmental pollution are primative, and are currently being refined. One may estimate the value of scenery pollution by determining how much people would be willing to pay annually or on a lump sum basis to be free from the offending pollutant. Alternatively, one element of cost may be estimated by calculating the decline in property values adjacent to drilling and production operations.

Other estimation instruments may also be developed. Nevertheless, any estimates of the social cost will be rough approximations indeed. However, in the past after having acknowledged the great difficulty of estimating these intangible social costs there has been a tendency to conclude that the cost cannot be estimated and thereby to treat the cost as if it were zero. A zero estimate of the social cost is among the worst estimates that could possibly be made. There is a need to further refine the analytical instruments to estimate social costs. But in the meantime an extremely rough estimate is probably better than none at all.

In addition to pollution as a social cost, there are biological resource costs which may result from marine mineral production. These may include fish, wild life and plant losses. An estimate of the social cost requires first some knowledge of the physical damage. Obviously, estimation of the biological resource cost involves interdisciplinary research. Economists can make their value estimate only on the basis of prior biological research.

There may also be labor and capital losses due to marine mineral recovery. For example, the Santa Barbara oil spill resulted in commercial fishing boats being confined to the harbor for a period of time. During this time, some fishing boats were idle and the cost to society takes the form of idle capital. Some fishing labor, excluding that labor employed in the clean-up process (which is a social cost itself), is a social cost as an unemployed resource. Further, pleasure boats were similarly confined to the harbor, and a social loss occurred due to this unused capital.

Finally, there may be a social cost due to a loss of tourism income. However, this loss may be more apparent than real. Again using the example of the Santa Barbara oil spill, if it can be shown that a specified number of tourists avoided the Santa Barbara area and as a consequence, a specified tourism expenditure was lost, it still does not follow that there is a social loss. There would be no social loss if the tourists who did not come to Santa Barbara instead visited another area and found available facilities there, and further that such tourists were indifferent between spending their leisure in Santa Barbara or the alternative location. In this event the tourism services were consumed with equal satisfaction, hence, there would be no social cost. The tourism loss is thereby confined to a private loss, external to the oil companies responsible for the oil spill, but nevertheless a private loss. On the other hand, if tourist facilities were not available in alternative locations and instead additional motels, for example, were constructed to meet the new demand leaving idle facilities in the Santa Barbara area, and further if the alternative locations were clearly inferior choices, then real social losses would be involved. Even in the latter situation, however, the social cost is probably relatively modest.

In the foregoing analysis of social costs we have made reference to a particular instance and to costs in an ex-post sense, that is after the fact. If social costs are internalized in such a manner that they will affect future decision making, then estimates of social costs derived from such incidents as the Santa Barbara oil spill, first must be restated in terms of a probability and a value of such social cost, and second must be allocated to a given lease. When this is done the ex-ante (before the fact) cost to be internalized is likely to be a relatively minor amount. We can show this additional cost in terms of Figure 1 by making a slight addition to the bars representing estimated operating cost for a given investment.

For oil investments the major adjustment resulting from calculation of a social rate of return is likely to occur in a restatement of expected benefits. Again, Figure 1 may be used to reflect this adjustment. The estimated time stream of revenues would be adjusted downward to eliminate the fictitious values created through government interference with the price mechanism, such interference occurring on behalf of segments of the oil industry. If the private estimates contain a fictitious value equal to slightly more than one-third of the current market value, then the time stream of anticipated revenues would be reduced by slightly more than one-third. Thus, it is probable that in the case of oil production the excess of anticipated benefits over costs would be substantially reduced. When these values are discounted to the present the probable effect is first, bonuses bid to the Federal Government for oil leases would have been substantially reduced and second, for the oil leases sold in the Santa Barbara channel it is probably true that most leases would have had a negative value. That is, potential buyers would have concluded that the leases offered were worthless and no bids would have been submitted.

CONCLUSION

If a free enterprise system is to produce an optimum allocation of resources as required for a high standard of living, optimum national security, and other goals dependent upon a high efficient economy, then it follows that external costs and benefits must be internalized and that unjustified interferences with the system of competitively determined market prices should be eliminated. Where uncompensated fail to reflect competitive forces, private enterprise in making critical investment decisions wastes resources either in over or under development. One means whereby net external costs may be internalized is to levy a tax on the offending industry equal to the reduction in total benefit resulting from the total operation. In instances where net external benefits accrue we have a prima facie case for a public subsidy equal to the amount of the net benefit accruing to society.[16] Only where monopolistic and unjustified governmental interference with the price system is absent, and where externalities are either absent or correctly internalized, will we achieve the happy harmony between private and social interests which Adam Smith described in his doctrine of the invisible hand.

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4. Ibid., pp. 16-18.

5. On a more technical level, full Pareto equilibrium cannot be reached by unilaterally imposing a tax on an offending firm in the case of an external cost and providing a subsidy in the case of an external benefit. Full Pareto equilibrium instead requires bilateral taxes and subsidies covering both parties in each externality situation. In the marine development environment many persons are involved as the "affected party." Due to incomparability of utility functions, a double tax-subsidy solution that attains full Pareto equilibrium is a practical impossibility For a full analysis of this problem see James M. Buchanan and Wm. Craig Stubblebrine, "Externality," Economica, N. S. Nov, 1962, 29, 371-384.

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7. Mead, Walter J., Testimony before the Committee on the Judiciary Subcommittee on Antitrust and Monopoly, 91st Congress, ... vention in the Market Mechanism, Part 1, pp. 77-102.

8. The case for government interference on behalf of the oil industry (at the expense of all consumers) has been made on the national security argument. This argument is commonly the basis for rationalizing a claim for government subsidies, whether in the indirect form of tariffs and quotas, or more direct subsidies. Only very recently have we asked whether the benefits are equal to the costs, or if there is a less expensi alternative means of meeting national security requirements.

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16. See footnote No. 5.

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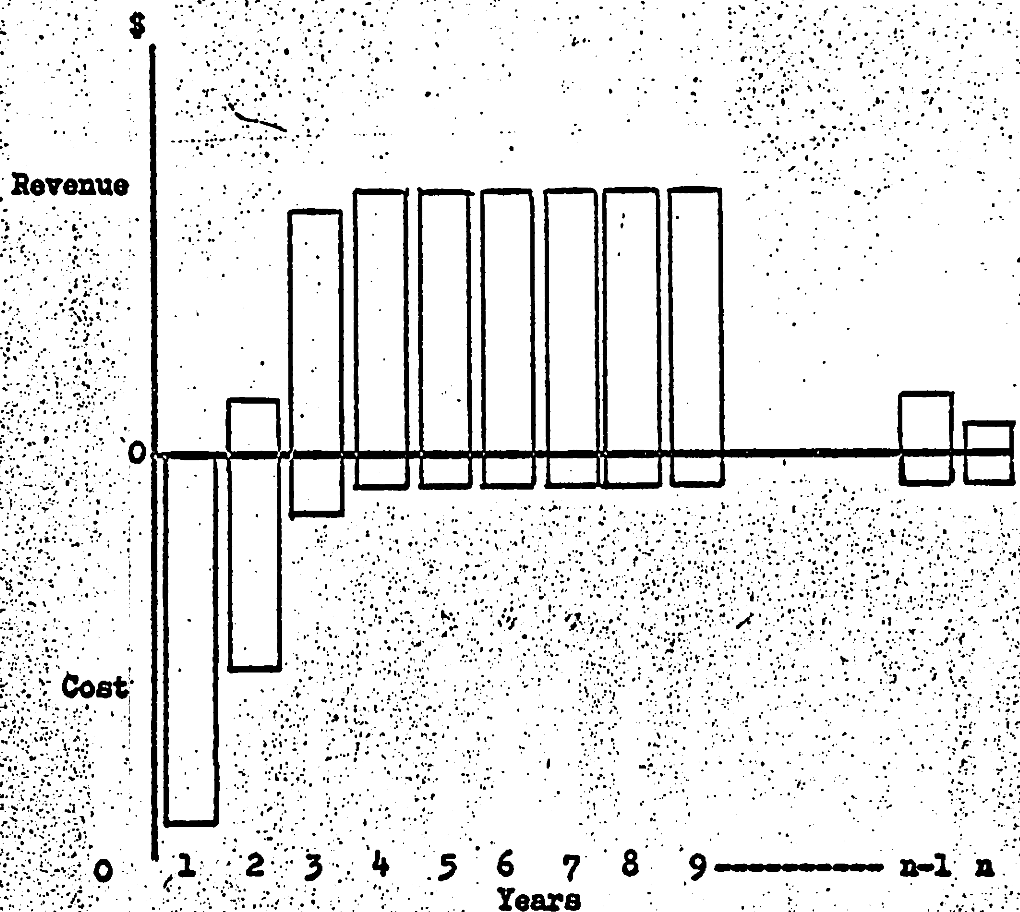

Fig. 1 - Model of future cost and revenue streams.

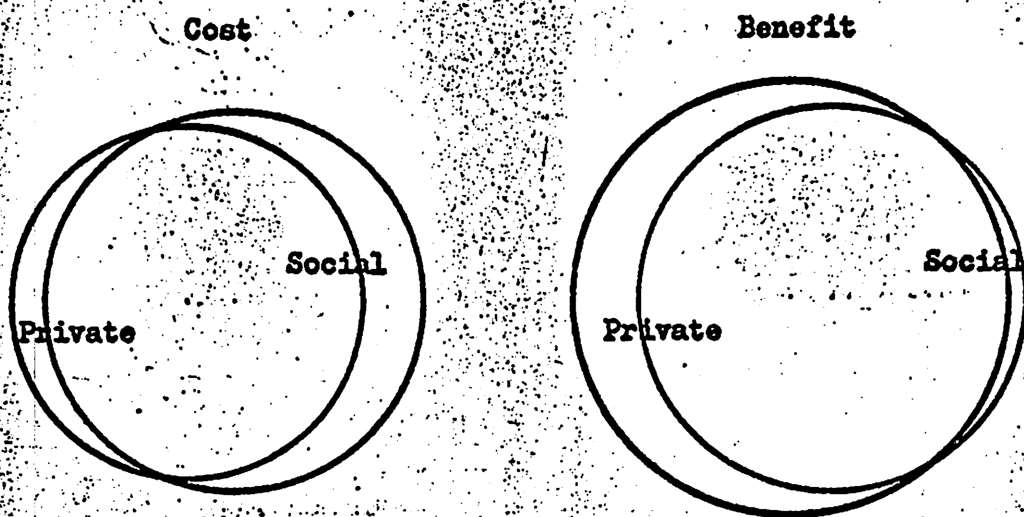

Fig. 2- Model relating private and social benefits and costs.

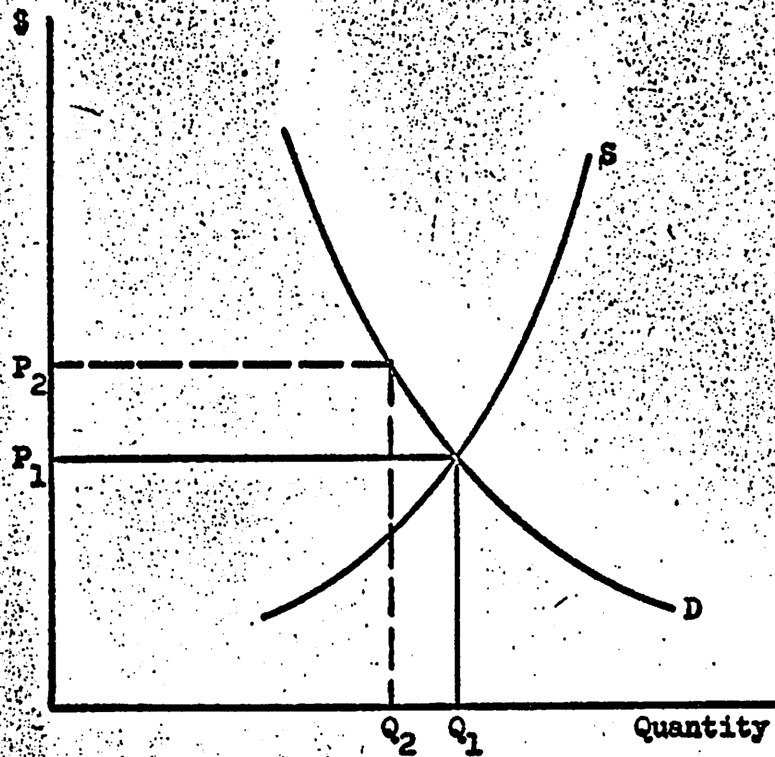

Fig. 3- Supply-demand model showing the effect of market demand prorationing.

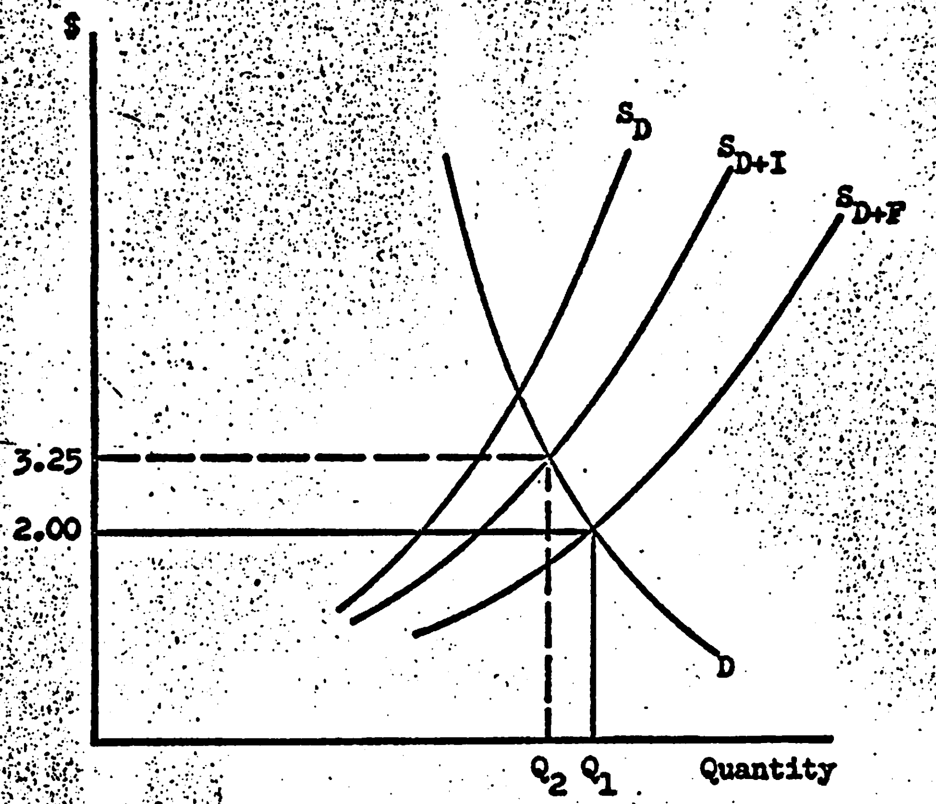

Fig. 4 - Supply-demand model showing domestic supply, imports, and foreign supply and demand relationship.

(3) following the wording of the 1958 Geneva Convention on the Continental Shelf, "beyond that limit, to where the depth of the superadjacent waters admits of the exploitation of the natural resources of the said areas." Thus, all areas outside the 200-meter countour are at least potential mining sites if U.S. firms are able to demonstrate an operable production system.

The closest known manganese–iron oxide reserves lie at depths of 350 to 1,000 meters on the Blake Plateau off the southeastern coast of the United States, an area of about 1,800 square miles. These reserves, estimated to total 1.45 billion tons, contain 20.5 percent MN_3O_4, 15.8 percent Fe_2O_3, 0.43 percent nickel, 0.3 percent cobalt, and 0.13 percent copper [10, p. 49]. All of these concentrations compare unfavorably in ore grade with available land deposits or with Pacific Ocean nodules. Reserves of manganese nodules in the Pacific have been estimated to be as great as 1.7 trillion tons [12, p. 175]. Their average composition is estimated to be 24.2 percent manganese, 14.0 percent iron, 1.0 percent nickel, 0.35 percent cobalt, and 0.53 percent copper [12, p. 180]. The enrichment of the nodules with trace minerals is a function of depth, however, and those deposits of economic importance may be expected to lie at depths of from 12,000 to 18,000 feet.

Supply and Demand Conditions

The recovery and processing of manganese nodules will result in significant output of manganese ore, cobalt, nickel, and copper. The principal use of manganese is in steel production to counteract the effect of sulphur and to impart various qualities of strength and hardness. Known world reserves (about 2 billion tons) are large relative to annual consumption of 16 million tons. Since 1964, the price of manganese ore has doubled from $30 to about $60 per ton in recent quotations. Since the demand for the ore is derived from the demand for steel, and since "there is no satisfactory substitute for manganese in the major metallurgical uses and manganese as a metal has no uses of its own" [5, p. 570], the demand should be highly inelastic.

Cobalt has a wide application in the making of high-strength steel alloys. World production averages about 15,000 tons per year, one-third of which is consumed in the United States. Known reserves are over 3 million tons. Prices have trended downward from $2.60 per pound in 1955 to $1.87 in 1967. Although its own price elasticity of demand may be close to one, the fact that its uses substantially overlap those of nickel means that any joint decline in prices following manganese nodule recovery would result in a smaller increment in quantity demanded for either mineral than that estimated by the conventional formula.

Principal uses of nickel are in stainless steel, nickel platings, nickel al-

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A Cost–Benefit Analysis of Ocean Mineral Resource Development: The Case of Manganese Nodules

PHILIP E. SORENSEN AND WALTER J. MEAD*

IN recent years, both popular magazines and scholarly journals have, in increasing numbers, heralded the imminent opening up of the "inexhaustible treasures of the oceans," leading some investment advisory services to conclude that ocean mining will be "the growth industry of the 1970's." At the same time, committees of the United Nations are studying the implications of ocean mineral exploitation for the underdeveloped nations, fearing the impending loss of major export sales and hoping to arrive at a "law of the sea" which protects these nations' presumed "natural right" to a basic inheritance of mankind. Is this optimism justified? And are there externalities connected with these developments of sufficient value that a case can be made for government inducements to growth? The present paper attempts to answer these questions by applying cost–benefit analysis to the most promising untapped ocean mineral resource, manganese nodules.

The Present Status of Marine Mineral Recovery

Although the oceans and the lands beneath them are potential sources of all minerals, only oil, natural gas, and sulphur are presently being produced in significant quantity. All other presently exploited ocean minerals, including tin, diamonds, sand, gravel, magnesium, bromine, and gold, represent less than 30 percent of the total value of mineral resources recovered from the ocean in 1964, estimated to be about $5 billion, one-third of this amount being attributed to U.S. production [6, p. 25]. At present the most important potential ocean mineral resources are phosphorite, a high-grade fertilizer available in great quantities on the continental shelves, and manganese nodules, porous, spherical concretions containing varying quantities of nickel, cobalt, and copper, which are widely distributed on the sea floor.

The relevant geographical areas from which a manganese nodule inventory is legally available for the United States are (1) the territorial waters over which states have jurisdiction, (2) the outer continental shelf beyond the boundaries of state jurisdiction to a depth of 200 meters, and

* We are engaged in a general study of the economics of ocean mineral resource development. We gratefully acknowledge the research support of the John Randolph Haynes and Dora Haynes Foundation.

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loys, and steel castings. World reserves are plentiful and widely distributed, totaling 70 million tons as compared to annual consumption of 400,000 tons, 45 percent of which is U.S. consumption.

Despite adequate reserves, the rapid growth in world demand for nickel since 1964 has resulted in shortages which have pushed prices from about 70¢ per pound in the decade before 1965 to 94¢ in 1968. A tight supply situation is expected to continue through 1970, but major new production facilities are now under construction, and these, together with continuing substitution of other metals for nickel in stainless steel, contribute to an expectation of stable or falling nickel prices after 1970.

Copper's major use is in the transmission of electricity, other uses being plumbing, automobile and home appliance manufacturing, and decorative and architectural applications. World copper production is expected to reach almost 7 million tons in 1968, of which the United States will consume some 30 percent. Estimated reserves of copper (270 million tons) are adequate, even in relation to the increased consumption levels expected in the next decades. The combination of a prolonged labor dispute in the United States and high military demand have caused extraordinary recent price increases for copper in free metal markets of the world. The present copper price (42¢) is not expected to persist beyond early 1969, however, because of excess stocks of copper scrap and loss of some part of the copper market to aluminum and plastics as a result of the strike. Technological advances in copper mining and processing have made it possible to mine ores containing as little as 0.3 percent copper in the United States, as compared to the 2-percent figure regarded as marginal fifty years ago [7, p. 62]. All these factors point to long-run stability in copper prices.

Private Costs and Revenues

In attempting to estimate the private costs and revenues which may be expected in exploiting manganese nodules as a resource, a massive information gap is immediately encountered. At almost every level of the production system, new and unknown processes must be applied, whose costs and operating characteristics can only be speculated upon. What follows, then, is not a listing of known engineering and construction costs for all parts of the system but instead the best available estimates, based upon history and analogy, drawn upon by government agencies and private firms and synthesized by the present writers. Where conflicts of opinion exist, we have generally sought to use conservative figures for costs at all stages in the total system and have likewise applied a conservative hypothesis concerning demand functions in estimating revenues.

Ignoring exploration costs, there are three connected production systems involved in manganese nodule exploitation: dredging, transporta-

tion, and processing. These systems will be described and cost estimates for them given separately. On the basis of the estimated proportions of minerals recovered from gross tonnage processed, a revenue estimate will be derived. The present value of the expected revenues will then be compared to the total investment required.

Dredging

There are no presently operative deep-water dredges; there are, indeed, no final engineering designs for such dredges, despite the profusion of fantasy models illustrated in various publications. As noted earlier, those manganese nodules of economic interest lie at depths of from 12,000 to 18,000 feet. To bring up materials from such depths will require a new hydraulic dredge capable of withstanding tremendous pressures, both from ocean depths and within the water column supplying the pressure differential. At the same time, the dredge line must be reasonably flexible, able to withstand current changes and adjust to the varying topography of the ocean floor. Despite attempts by promoters of ocean mining to explain away these difficulties, it appears that the deep-water dredge will require an order of creative engineering to date unknown in world mining. Attesting to the limits of present technology, a recent survey of available undersea mining equipment noted that suction dredges operate at depths of from 30 to 90 feet "but are being built to operate at depths up to 250 feet" [17, p. 112]. The adjustment of production techniques required to move to 18,000 foot depths is clearly not a simple, continuous function; it is a technological challenge of an entirely different order.

What will it cost to develop and produce a practical deep-sea dredge? Some experts confess that they don't believe such an engineering feat is within the financial capacity of any private firm; some say that a deep-water dredge simply won't operate.[1] Engineers at the Bureau of Mines express the belief that such a dredge could cost as much as $150 million.[2] When this figure was put to a managing engineer for one of the world's largest dredge manufacturers, he agreed to it only as a minimum estimate.[3] Further evidence of the magnitude of the required investment was given by a speaker at a recent oceanography conference, who used the figure $200 million as the amount a major mining firm has "agreed to commit" over the next decade in research, prototype construction, and final system construction for manganese nodule recovery and processing.[4]

[1] They believe that the nodules will lodge in the joints of a flexible system—that only a vertical dredging column is capable of generating the required lift, and that a "telescoping" vertical column cannot be built to operate in this environment.

[2] Conversation with M. J. Cruickshank, Marine Minerals Technology Center, Tiburon, California, June 6, 1968.

[3] Conversation with K. W. Posselt, Standard Dredging, Inc., New York City, June 24, 1968.

[4] A confidential confirmation of this figure was given us by a consultant to the proj-

We believe it reasonable to conclude that the capital cost of the deep-water dredge required to recover 5,000 tons of nodules (net dry weight) per day (averaged over 360 days, on the hypothesis of 250 working days per year and 18 hours per working day of operations)[5] will be $150 million.[6]

In the absence of design specifications for the deep-sea dredge, operating costs can only be roughly estimated. Welling and Cruickshank note that large conventional dredges already require over 10,000 horsepower [17, p. 113]. We assume that the proposed system, with greater pressure requirements, using an underwater vehicle and possibly carrying a television camera on the ocean floor, would require a minimum of 15,000 horsepower. The power costs alone would then be in the neighborhood of $1.5 million per year (at 2¢ per operating horsepower hour). Conservatively estimated, additional costs of $7.5 million in operation and maintenance and $7.5 million in insurance[7] would bring the yearly operating costs of the dredge alone to $16.5 million.

Transportation[8]

Transport of manganese nodules will require an almost continuous movement of ore-carrying barges from the point of recovery to processing plants in the United States. The costs of operating this fleet can be more accurately estimated than were dredging costs, though the optimum ship design for this purpose is still unknown. Consideration of a number of alternatives has led us to conclude that the least-cost method of transport for nodules would be a system of barges, pulled by ocean-going tugs, and moving in a continuous cycle to and from the recovery site. Construction costs for the required barge (having an ore-carrying capacity of 10,000 short tons) is about $550,000. Annual maintenance costs of about 5 percent of original cost and insurance costs of 2.5 percent of insured risk per year could be anticipated. Ocean-going tugs of the type required may be chartered at $1500 per day, which we regard as a competitive exemplification of the total operating cost of such a vessel. The original mining sites are expected to lie in the South Pacific, some 4,000 nautical miles

ect. He agrees with us that only a small part of this amount will be spent unless some major change in conditions of demand or supply takes place.

[5] Gross tonnage dredged would be much higher; water, sand, and silt would be screened out on the receiving barge. Cf. Webb [16, p. 12], who reports an average gross dredging rate of 2,340 tons per working day at depths of from 35 to 100 feet in sea diamond mining.

[6] Mero estimates the cost at $7.2 million [12, p. 270]; Brooks uses a figure of $100 million, including processing facilities [4, p. 85].

[7] Transport barges of the type required for the system carry a rate of about 2.5 percent of insured risk per year. Prototype undersea vehicles carry rates of 25 percent and higher, if insurance is available. (Communication from Royal Globe Insurance Company.)

[8] This section was written with the assistance of J. R. Paulling, Professor of Naval Architecture, University of California, Berkeley.

from the (expected) location of the processing plant (near Los Angeles). The speed of these vessels ranges between 9 and 11 knots. We therefore conclude that a fleet of 18 barges and 16 tugs will be required to complete the 180 round trips associated with one year's operation. A port facility with specially designed off-loading equipment will also be required, the cost of such a facility being about $5 million, with an annual cost for labor, maintenance, and power required for off-loading of about $1 million. Summing up, the transportation of manganese nodules will require an investment of $15 million and annual operating costs of about $10.5 million.

Processing

Manganese nodules are a true mineralogical phenomenon, and the best energies of a number of outstanding chemists and geologists have been devoted in recent years to unraveling the mysteries of their origin and geochemical properties. There is no way adequately to summarize the difficulties of extracting trace minerals from manganese nodules without entering into some discussion of complex chemical and mineralogical relationships such as oxide phases, lattice structure, and chemical reaction functions. It may be concluded, however, that the difficulties of selective leaching are such that no immediate or simple process of obtaining large proportions of the contained trace minerals from manganese nodules is now known or anticipated. Functional characteristics of the most commonly suggested process of extraction (using an acid leach) are described in detail by Hoover [8, pp. 29–64]. Despite his optimism, the acid leaching process has several apparent drawbacks: the dissolution of copper and nickel from the nodules takes an extraordinary length of time, requires an unacceptable quantity of acid as an input, and results in high cobalt dissolution only where the iron content of the nodule is low (less than 5 percent). The later separation of the cobalt from the nickel in solution, while theoretically possible, appears to be both difficult and expensive. Present indications are that technical and economic factors rule out acid leaching, direct smelting, sulphur dioxide leaching, and other direct reduction methods. A recent intensive study concluded that the most effective extractive method involves a reductive roast-ammonium carbonate leach process.[9] Using this process, the maximum percentages of contained minerals extracted (depending upon the presence of oxygen) were 75 percent Mn, 78 percent Fe, 85 percent Co, 90 percent Ni, and 10 percent Cu [15, p. 2].[10] The capital cost of a processing plant capable of handling 5,000

[9] The study [15] was made at the Bureau of Mines Metallurgy Research Center in Salt Lake City. Further conclusions of the study have been reported to us by Mr. L. Schack, director of this research.

[10] We have employed even larger recovery percentages in our revenue estimates, ac-

tons of manganese nodules per day is estimated (in this same study) to be $50 million. The estimated variable cost of processing nodules using this system is $30 per ton, although the figure could fall as low as $25 per ton in the future, as we have assumed in the cost calculations below.[11]

Employing the accepted estimate of the average proportions of contained minerals,[12] a plant processing 5,000 tons of manganese nodules daily (or 1,800,000 tons yearly) and recovering maximum percentages of the contained minerals would recover 585,000 tons of manganese-iron ore, 17,100 tons of nickel, 5,760 tons of cobalt, and 1,908 tons of copper.

If the present prices of these minerals are used as estimates of future prices, the annual gross revenue generated by the system is about $90 million. Yearly operating costs (combining the estimates developed above for the three phases of the system) total $72 million. Discounted at 6 percent, the present value of net operating revenue is about $99 million, as compared to a capital cost (discounted to allow for a five-year development period) of $175 million.[13]

When account is taken of the expected change in prices brought about by the increased supplies made available, the outlook is blacker still. In Table 1, current world production of the relevant minerals is compared with incremental outputs, and the proportions are then used to predict the percentage decline in market price which would occur if price elasticities of demand are assumed to be unitary for all outputs.

At these more realistic price levels, total revenue would fall to about

counting for possible increases in efficiency: 85 percent for Mn and Fe, 90 percent for Co, 95 percent for Ni, and 20 percent for Cu.

[11] This is also the figure used by Mero [12, p. 272].

[12] For example, 24.2 percent Mn, 14.0 percent Fe, 0.99 percent Ni, 0.35 percent Co, and 0.53 percent Cu [12, p. 180].

[13] An appendix giving details of these calculations is available from the authors upon request.

Table 1. Expected change in prices of minerals as a result of increased supplies from marine recovery of manganese nodules

Mineral	Present world output	Increase in world output	Percentage increase in output	Percentage decline in price, assuming unitary elasticity of demand[a]
	thousand tons		*percent*	
Manganese ore	18,000	585.00	3.25	3.13
Nickel	450	17.10	3.80	3.67
Cobalt	15	5.67	37.80	27.43
Copper	7,000	1.90	Negligible	Negligible

[a] The actual elasticities, we believe, would be lower; the assumption of unitary elasticity is made for purposes of comparison only.

$81.6 million, the present discounted value of net revenue (at 6 percent) falls to $53 million, and the prospective capital loss becomes $122 million. At any higher rate of discount (which would approximate the degree of risk involved), the loss would obviously be greater still.

Social Costs and Benefits

Given this dismal outlook for profits in mining manganese nodules, why does the prospect continue to excite interest among a number of major American firms? We believe that there are two explanations. First, mining companies must, for defensive reasons, engage in sufficient individual research to assure themselves full knowledge of the economic potential of marine minerals which could eventually destroy their present markets [13, p. 182]. And second, it is widely believed that the United States (or even some foreign governments) may, in the near future, be willing to underwrite all or most of the basic exploration and prototype construction required for marine mining. Many firms are willing to enter the field under these circumstances and are presently preparing their credentials.

The likelihood of federal assistance to undersea mining in the explicit form now hoped for depends upon a number of political or international exigencies, but from a purely economic point of view should be based solely upon an evaluation of the social rate of return which might be expected on the investment involved. In a recent study [11, pp. 11–14], we have attempted to identify and give some order of magnitude to the major external costs and benefits associated with marine mining generally. For the specific case of manganese nodules, the principal external cost is likely to be associated with disposal of detrital materials in the ore beneficiation process at sea, which could have a major effect on the ecology of the area. The great distance of anticipated mining sites from inhabited areas obviates the additional forms of environmental pollution which would be observed in near-shore mining. Problems of disposal of wastes from processing plants on land and navigational hazards attributable to the mining and transport of the nodules are not unique to this industry, and recreation site destruction is unlikely so long as processing facilities are located in industrial areas. Thus, external costs peculiar to the contemplated system appear to be negligible.

There are, however, some significant external benefits: (1) pure research benefits flowing from enhanced knowledge of the ocean floor, (2) national defense benefits connected with increased engineering capability in the underwater environment and improved knowledge of undersea geology, and (3) technological spillovers, affecting follower firms in the same industry as well as firms in other industries.

The most important of the listed benefits is likely to be technological spillover effects. A new industry, employing radically different or complex technology, will experience a fall in production costs as it matures, both through physical improvements in the capital used and through greater understanding of the production process. For example, the deflated cost of producing rayon declined from about $1.15 per pound in 1930 to $0.58 in 1940 and to $0.38 in 1950 [11, p. 14]. The cost of sea water desalination by various methods declined from an estimated $10 per 1,000 gallons in 1960 to $1.15 in 1963, $0.80 in 1965, and $0.50 in 1968 [14, pp. 1, 16]. Nuclear power generating costs have similarly declined from about 50 mills per kwh in 1958, to 6.2 mills in 1962, and to 4.4 mills in 1964, a cost improvement for the most part attributable to the construction of larger generating units [2, p. 20; 3, p. 21]. Cost reductions flowing from rapidly changing technology are distinct from and in addition to what has been called the "learning curve," a reflection of increased operating efficiencies as workers accumulate experience in handling a new process in the context of a nearly constant technology [1, p. 87].

Some increase in the efficiency of transporting and processing manganese nodules attributable to both of these causes may be expected (and for the processing phase are allowed for in the cost estimates given above), but any dramatic improvements will likely occur in the manufacture and operation of the deep-water dredge. Second-generation dredges, engineered in the light of experience gained by the pioneering firm, may produce much higher recovery levels. It is impossible for such benefits to be completely internalized by patent protection, for neither knowledge diffusion nor imitative art can long be controlled. So it will pay to wait, to be the second or third firm in the industry. And, in time, firms in other industries which now use conventional dredges will similarly enjoy the benefits of a perfected technology for whose development they have not paid.

Thus the question is posed: Are the external benefits of deep-water mining sufficient that a reasonable case can be made for direct federal assistance? The analysis in our section on the present status of marine mineral recovery indicates that, under optimistic assumptions concerning demand elasticities and discount rates on expected net revenues, a manganese nodule mining system would, at present, result in massive capital losses. Furthermore, we see little cause for optimism that the prospect for profitability will improve in the next decade. The existence of large, untapped land-based reserves of all the contained minerals, together with continuing improvements in the technology of extraction and processing, make it unlikely that conditions of supply will force general price increases. Any revolutionary breakthrough in techniques of processing manganese nodules would immediately open up vast new reserves of low-grade ores on land, obviating the need for ocean mining. And there is no reason to assume that the estimated pioneering costs of a deep-water dredging system will fall in the future.

It is difficult to place values on the major external benefits of the system—technological spillovers to other industries, pure research benefits, and national defense benefits; but these values would not, in our opinion, equal the present cost to society of the investment required. We conclude that there is not, at the present time, a sufficient prospect of private or public reward for any major investment in manganese nodule exploitation to be economically justifiable. Continued defensive maneuvering by interested firms and widespread publicity which even now threatens ocean mining with "promotional overkill" should not distract us from recognition of cold, economic logic.

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A NEW ECONOMIC APPRAISAL OF MARINE PHOSPHORITE DEPOSITS OFF THE CALIFORNIA COAST

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Abstract

The assumption that an ocean mineral "bonanza" in the form of marine phosphorite lies open to exploitation off the coast of California is seriously disputed in this paper. Analysis of (1) the limited market for phosphates on the West Coast; (2) the costs of mining, beneficiating and transporting marine phosphorite; (3) the massive size of competitive land-based reserves and production capacities; and (4) the absence of any net social benefit connected with phosphorite mining which might justify federal subsidization of initial ventures in the area leads us to conclude that the off-shore California phosphorite deposits will not be economic to mine in the foreseeable future.

INTRODUCTION

This paper will attempt to estimate the present and potential economic significance of the marine phosphorite deposits lying off the coast of Southern California. For reasons that will be made clear in what follows, we have not made any detailed investigation of other marine phosphorite sites, such as the continental shelf areas off Florida, Baja California or Australia, although these areas are known to be potential sources of marine phosphorite from geological surveys. We believe that technological and economic factors point to non-U.S. sites as having the greatest immediate economic potential. Until these foreign sources come into production and yield positive economic results, the Southern California sites must be considered sub-marginal given the present structure of markets and competing sources. We recognize that the immediate availability of marine phosphorite deposits so near to California markets has stimulated considerable interest in their profit potential. Our paper will evaluate the findings of other investigators and will present a new set of conclusions based upon both private and social costs and revenues (or benefits).

The widely accepted estimate given by Emery [8, p. 319] that some one billion tons of phosphorite is deposited off the coast of Southern California explains the interest in mining this resource. The most attractive deposits are those located at reasonably accessible depths (up to 1000 feet) and in required concentrations (a minimum of five pounds per square foot). It has been assumed that these marine phosphorite deposits might be competitive with present sources in Florida, Idaho, Wyoming and Utah. Whether or not they are economically feasible to mine depends upon five considerations:

(1) The size of the market open for penetration and the expected market price.
(2) The technical cost of dredging, beneficiating and transporting marine phosphorite.
(3) The risk premium required in offshore operations.
(4) The <u>in situ</u> resource cost; <u>i.e.</u>, the policy of state and <u>federal</u> governments in <u>respect</u> to lease arrangements.
(5) The likelihood of any tax subsidies from state or federal governments.

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*The authors are currently engaged in a general study of the economics of ocean mineral resource development. Research support provided by the John Randolph Haynes and Dora Haynes Foundation is gratefully acknowledged.

In the sections which follow, each of these points will be explored.

CURRENT AND PROSPECTIVE MARKETS

The current demand for phosphate rock in California is variously estimated at from 350,000 to 450,000 tons annually. Adopting 500,000 tons as an optimistic figure and compounding at the predicted market growth rate of 6% per year, the total demand for phosphate rock in California will double by 1980 and reach 3 million tons annually by the end of the century. But even this dramatic growth will present a minor challenge to present suppliers. The estimated reserves of phosphate rock in the United States exceed 7 billion tons; "potential reserves" inferred from geological data, are estimated at an additional 49 billion tons in the U.S. alone [15, p. 704].[1] One calculation has shown that, assuming a rate of population growth equal to past trends (7.4 billion world population in the year 2000) and projecting present rates of increase in phosphate rock consumption to that date, aggregate world consumption of phosphate rock, from 1966 through 2000 A.D., will equal only 7.6 billion tons [12, p. 60]. By no stretch of the imagination can marine phosphorite be considered a strategic reserve commodity.

California presently imports all its phosphate rock from Florida and the Western states. Should phosphorite become available from offshore sites, it would not completely displace these current sources, even if lower prices were offered, for the reason that a major share of the imported rock is processed by firms either vertically integrated to the mines or tied to Florida producers by long-term contracts. Earlier studies of the market for California phosphorite have stressed the potential for exports to Japan and the South Pacific [25, pp. 160-167]. These exports (currently about 2.5 million tons per year to Japan and Asia) would be an attractive incentive to potential investors if delivered prices from Florida could be undercut. Nevertheless, the long-run outlook for these export sales cannot be considered bright, we believe, because whatever improvements and demonstrations of working production systems occur in operations off the Southern California coast must surely be transferable to the equally rich resource sites off the coasts of Australia or India, and these sources will then undersell California producers through savings in transport costs alone, ignoring other possible savings. The long-run prospect, then, is that California phosphorite can command only a portion of the limited West Coast market, sharing that market with fertilizer and chemical processors whose captive mines in Florida will, in all likelihood, continue to operate.

COSTS OF PRODUCTION

There are widely diverse estimates of the cost of dredging marine phosphorite. Mero's 1960 estimate of $4.50 per ton [20, p. 53] has encouraged great interest interest in the economic potential of these resources.[2] Hess, for example, has adopted Mero's prediction [13, p. 88]. Overall's recent study [22, p. 62] adopts Mero's $4.50 figure for mining costs as a working hypothesis, concluding that the indicated spread between this figure and a maximum permissible figure for "mining, washing, drying and grinding costs" of $8.26 leaves open the possibility of a profitable California operation involving exports to Japan. Estimating on the basis of 600 foot dredging depths, Isard and Choquill concluded that the cost per ton mined

[1] Potential land-based world reserves are over 150 billion tons, op. cit.

[2] Mero earlier set mining costs at "$4-7 per ton depending on the depth of dredging and the mining method used" [19, p. 72].

would be $11.69 [14, p. 7], much closer to Mero's estimate of the costs of recovering manganese nodules at 1000 foot depths also using a drag dredge (between $11.50 and $12.10 per ton) [19, p. 257]. Translating the cost projections given by Davis and McKay [7, p. 69] for bucket line dredges operating at 200 foot depths and recovering 100 cubic yards (75 short tons) of materials per hour (or 1200 short tons per operating day, which could be then beneficiated to yield about 600 tons per day of nodules) we deduce that the capital costs of the required dredge would be approximately $8,000,000; the direct cost per short ton of materials dredged would be $1.00 (or $2.00 per ton of nodules). Maintenance costs of the dredge are included in direct costs, though no obsolescence factor is calculated. Assuming the minimum rates of marine insurance are applicable (2.5 percent of insured risk per year), annual insurance costs for the dredge alone would be $200,000.[3] A minimum opportunity cost for the capital invested in the dredge (considering the risk factor) is 10%. The rental cost of the dredge, therefore, would be about $3500 per operating day. The estimated total costs would then be about $8.00 per ton of nodules dredged. It should be assumed that the costs of dredging at greater depths (the target depth of most surveys is 600 feet) would be higher. Consideration of this figure and the estimates earlier cited leads us to conclude that the cost of dredging phosphorite nodules is likely to range between $10 and $12 per short ton, at an annual production rate of 180,000 tons.

Earlier studies have assumed that marine phosphorite can be upgraded to the required 31% P_2O_5 concentration by simple calcination. The cost of this process, depending on the richness of the original nodules, would range between $1 and $2 per ton. Indications are, however, that marine phosphorite contains excessive quantities of iron oxides and other impurities which limit the potential uses of the phosphorite and reduce its market value, irrespective of P_2O_5 content. To submit the phosphorite to the necessary chemical process of upgrading — presumably involving an acid leach — would add an unknown but considerable cost to the product.[4] It must be assumed that a product comparable to current land-based phosphate rock can be derived from marine phosphorite only at an additional beneficiation and processing cost of from $2 to $5 per ton.

Our estimate of the costs of transporting nodules from the mining site to the port of Los Angeles (between 100 and 200 miles, RT) is adapted from a recent study by Miller of the economics of bulk carrier operations [21, pp. 277-287]. That study was designed to point out the general economic desirability of barges versus ships. Annual transport costs for dry bulk carrying barges on a coastwise service whose RT operating route was 850 miles long, were estimated to be $1.33 per short ton at a minimum [21, p. 280]. Inference from Miller's table of annual transport costs as a function of various distances [21, p. 280] leads us to conclude that the similarly computed costs for a RT distance of 200 miles would be 70¢ per short ton. Miller's estimates do not include overhead, depreciation, taxes, loading or unloading costs and apply to a relatively large (780,000) total yearly tonnage, thus including some economies of scale not anticipated in a marine phosphorite venture. We believe it is reasonable to assume that transport costs alone will be approximately $1.00 per ton minimum.

A separate docking and unloading expense has not been included in previous studies of marine phosphorite. This cost is by no means negligible. It is possible to off-load bulk cargoes using automatic machinery, as in the

[3] Communication from Royal Globe Insurance Company.

[4] Leaching would cost a minimum of $5 per ton according to one University chemist.

Great Lakes iron ore transport, but this presumes tremendous volume — not a possibility in the case of phosphorite. Inquiries to shipping agents and harbor department officials have produced varying estimates for unloading costs depending on barge size, contract period, frequency of unloading and other variables. The harbor fee alone (collected by the City of Los Angeles) is 45¢ per ton. The costs for unloading run from $1 to $2 per ton. Since there may be possible modifications of the barges used in the operation which will simplify unloading, we have estimated the cost of this phase of the operation to be from $1.00 to $2.00 per ton. Our estimated total transport costs (including off-loading) of $2 - $3 per ton may appear high in relation to the cost of transporting phosphate rock from Florida (about $5.00 per ton). The latter figure is made possible, however, only by backhauls of rice and other commodities from California to Florida, and the phosphate shipments, therefore, carry only about half of the RT costs.

OPPORTUNITY COSTS AND RISK FACTORS

It is not commonly recognized that the attractiveness of any potential investment in marine phosphorite recovery cannot be determined on the basis of absolute expected profits independently of (a) "opportunity costs," facing the individual firm; and (b) the range or statistical distribution of possible profits. Potential operators will first consider alternative investment opportunities in current (known) processes or activities. And if the "maximum likelihood" estimates of profits in a new or untested endeavor exceed rates of return available in known activities, the variance of the (expected) distribution of potential profits in the pioneering process will then be considered in reaching an investment decision. Presumably, the greater the variance of the distribution of possible profit outcomes, the higher the risk premium which must be attached to the activity. A look at rates of return currently realized by firms potentially interested in phosphorite gives some indication of minimum levels of return that must be anticipated in marine mining before practical operations take place. Gulf Oil Corporation, for example, realized net income after taxes of 13.1% of invested capital in 1967. The comparable (1967) figure for Union Oil was 11.2%; for Lockheed, 15.5%; for Texas Gulf Sulphur, 26.4%. Considering the risk involved in a phosphorite venture from the point of view of both costs and eventual markets, it is not unreasonable to predict that expected net rates of return on investment in marine mining of from 30 to 40 percent will be needed to bring the required capital on line.

LEASE POLICY

Since Southern California phosphorite is found on the continental shelves within the jurisdiction of the federal (and in some cases the state) government, a question arises as to possible payments for leasing rights. No firm will make the major investments required for phosphorite mining in the absence of some clear understanding regarding a legal regime permitting exclusive development and exploitation. The accepted procedure in the case of federally owned resources is to offer leases for sale at public auction. It was in this manner that Collier Carbon and Chemical Company (a subsidiary of Union Oil Company) obtained leases on 30,240 acres of the continental shelf on the Forty Mile Bank off the coast of San Diego. Collier (the only bidder) paid $4.03 per acre in leasehold bonuses, and entered into active exploration and dredging of the area during 1962 and 1963. The company dredged up several unexploded naval shells remaining from a gunnery range used during World War II and on the discovery that the area was not "clear and mineable," as the lease agreed, was awarded a full refund of the bonus payment by the Bureau of Land Management. Our conversations with Union Oil Company personnel connected with the Collier experiment (as expected) produced no detailed explanation of Collier's findings during the pilot operation. This information is regarded as

proprietary. However, we did learn that the quality and quantity of nodules dredged were "disappointing" and that dredging in an uncontrolled environment is more difficult and unpredictable than is assumed in any of the known project studies, most of the latter being based upon dredging operations involving such minerals as cassiterite, conducted in sheltered coastal waters.[5] The presence of the naval shells, while clearly representing a risk, provided (it would appear) a happy pretext for escaping from an uneconomic contract.[6]

The effect of the Collier experience, in the years since 1963, has been dramatic. No further phosphorite leases near California have been requested and neither Union Oil nor any other firm has felt that sufficient economic incentives exist to stimulate development of a successor production system. As one observer recently put it, if any future off-shore phosphorite venture is to succeed, "The various governments involved must provide incentives to the risk takers more liberal than the policies in effect at the time of the Collier Carbon lease" [22, Nov. 1968, p. 52]. Whether or not federal and state governments have sufficient reason for providing incentives to potential phosphorite operations in the form of subsidies or otherwise is the subject of the next section.

EXTERNAL COSTS AND BENEFITS

Given the discouraging outlook for profits in mining marine phosphorite, why does the prospect continue to excite the interest of a number of American firms and private individuals? We believe there are two explanations. First, some companies must, for defensive reasons, engage in sufficient individual research to provide themselves with protective knowledge of resources that could strongly affect their present markets [18, p. 1618]. This "watchful waiting" is typical of competitors on the fringes of a new industry. And second, there is some possibility that the federal government may, at some time in the future, be willing to subsidize initial ventures in marine mining. Many firms would be willing to enter the industry under these circumstances and are presently preparing their credentials.

The likelihood of federal assistance to undersea mining in the explicit form now hoped for depends upon a number of political or international exigencies, but from a purely economic point-of-view should be based upon an evaluation of the net benefit to society, computed in the form of a social rate of return on the investment involved. In a previous study [17, pp. 11-14], we have attempted to identify and give some order of magnitude to the major external costs and benefits likely to be associated with marine mining generally. In the case of phosphorite, the major external cost is likely to be associated with waste disposal at sea, assuming that the phosphorite undergoes initial beneficiation at the dredge head. So serious are the prospective effects on the ecology of near-shore areas as a result of contamination with mine tailings that there is no possibility, given the present "conservation minded" political climate, that the California state government would permit either dredging or waste disposal in waters under its jurisdiction.[7] The federal government has

[5] For some reason the environment difficulties experienced by Marine Diamond Corporation in dredging off the coast of South Africa between 1961 and 1965 seem not to be similarly analogous [25, esp. p. 8].

[6] We have recently been informed by a Union Oil Co. official that Collier was required to stop dredging in the area by the U.S. Navy after the shells were discovered. Thus, the bonus payments had to be refunded, and no other leases in the area will be permitted until a determination is made that accidental explosions cannot occur.

[7] This fact has been confirmed by an active ocean mining firm in a private communication.

recently come under widespread criticism for improper control of offshore oil drilling and inability to limit the use of chemicals such as DDT, in both cases leading to damage to many forms of life in the ocean. Any process involving waste disposal (particularly if toxicants are discharged) in federal waters will be scrutinized more closely now than has ever before been anticipated.[8] It is not without reason that mining firms look upon U.S. controlled waters as the most strictly regulated environment in the world ocean.

Other external costs associated with phosphorite mining are less important: increased navigation hazards and noise creation, the latter relevant only to dredging nearer to shore than is presently contemplated.

External benefits are likely to be smaller still, however. In an earlier study [18, pp. 1618-1619] we discussed the significance of technological spillover effects which occur when a new or innovative technology is applied to a basic process and later becomes available (at no additional cost) to other firms or sectors of the economy. In this situation, a case can be made for subsidy payments to the innovating firm equal to society's net "spillover" benefit. Phosphorite mining is unlikely to involve any major departure from conventional dredging and transport. It is true that beneficiation processes may be developed out of the marine phosphorite experience which will open other land-based phosphorite sources to exploitation which are currently sub-marginal. The irony of this case is that marine phosphorite spillover benefits could then be said to have destroyed their creator. The benefits of such a breakthrough would accrue to the phosphate industry generally, probably including the firm whose marine phosphorite experiments brought about the new techniques. So tenuous is the argument for social subsidy in this case that it would be wise to ignore it in computing the net social effect of phosphorite mining. In summary, we find (1) no basis upon which a case for federal subsidization of marine phosphorite production can be built; and (2) sufficient cause for concern over environmental pollution to support strict federal regulation of off-shore dumping of wastes. The fact that phosphate production in Florida and the Western states creates major pollution problems [See 7, pp. 60-61 and 3, pp. 158-59] stands as a warning. It will be difficult to shift this kind of pollution to another site.

SUMMARY

Our survey of expected private costs of Southern California phosphorite production points to the following cost ranges as minimum estimates:

Dredging	$10 - $12 per ton
Beneficiating	$ 2 - $ 5 per ton
Transporting, off-loading	$ 2 - $ 3 per ton
Land transport (100 miles)	$ 1 - $ 2 per ton
TOTAL COSTS	$15 - $22 per ton

These figures may be compared to present prices for phosphate rock delivered from Florida or Idaho, varying from $12 to $16 per ton, depending upon grade and source [16, p. 32]. Further emphasis of the uneconomic character of the Southern California phosphorite deposits is added when these additional facts are considered:

(1) The phosphate rock industry has in recent years fallen into a serious economic recession brought about by significant increases in domestic production and the opening up of increased capacity throughout the world. In mid-1968, some 15 to 16 million tons of rock (about 40% of that year's output) were in inventory in the U.S. alone [3, p. 158]. By means of shutdowns and curtailments, the industry averted an even greater crisis [11, pp. 66-67]. Despite this unfavorable economic climate, new investments in phosphate rock production facilities added some 7.2 million tons per year to U.S. capacity in 1968. Significantly, one project which was terminated in the face of the poor economic outlook for the industry was the development by New Idria Mining and Chemical Company of an 1800 acre phosphate deposit near Bakersfield, California [23, pp. 98-102]. This deposit would presumably enjoy a competitive advantage over marine deposits and would therefore enter production for the California market prior to offshore production.

Omitting the U.S.S.R., present investment projects in other parts of the world will add between 18 and 20 million tons per year to annual capacity in the next three years, and these figures do not include two massive foreign projects: the first involving development of the world's largest phosphate deposits in the Spanish Sahara, which will add (initially) 10 million tons per year to outputs; the second involving continuing investments in projects in Morocco which are designed to add 18 million tons to yearly capacity by 1975 [23, pp. 98-102]. These projects assure fierce competition for American export markets (about 11 million tons in 1968) in the future and do not encourage commitment to the development of offshore phosphorite in so risky a situation as that presented by the California sites.

(2) The Collier experience does not represent the only serious look by operating firms into the feasibility of mining the Southern California phosphorites. International Minerals and Chemical Corporation entered into a joint study venture with Lockheed Aircraft Corporation in the fall of 1963 and spent two years evaluating the business opportunities offered by ocean exploitation. After considerable investigation, including sample dredging, they concluded that the economic prospects for California phosphorite were negative. Global Marine, Inc., has also explored these sites and reached a similar negative conclusion concerning their present value.

(3) Our cost estimates (above) have not included allowance for exploration and leasing costs, royalties, or taxes. If open sea disposal of dredging wastes is not permitted, our cost figures for transportation and unloading would have to be doubled and an additional cost added for on-land disposal of waste materials. Considering the costs of comparable by-product disposal in the Florida operations, this expense together with the other added costs would push the delivered cost of phosphate from these off-shore sites above $20 a ton (minimum).

(4) In spite of many programs by government agencies and private firms to accomplish exhaustive sea-floor sampling, we know very little about the quality and quantity of phosphorite lying off our coast. Resource delineation is an expensive, painstaking process. There has been too little coordination of exploration and research activities. For example, some published and widely-quoted figures concerning P_2O_5 content in dredged samples from various sites off the California coast were later found to be exaggerations for the simple reason that surface areas of the samples alone were tested and these contained the highest concentrations of the desired compound. Recent extensive sampling by scientists from the U.S. Bureau of Mines on the Coronado Bank, in contrast to earlier findings, revealed the surprising results that 85% of the sand ran less than 1% P_2O_5 (upgradable to 4% by screening) and that the average P_2O_5 content of all materials dredged was only 3.29%[9] While the character of all potential California mining sites

[8] Any doubt concerning the potential ecological damage caused by dredging and attendant waste disposal is disspelled by George Laycock in his article, "Deep in the Mud of Texas," Audubon, Nov./Dec. 1968, pp. 98-118.

[9] P. C. from B. Barnes, Marine Minerals Technology Center, Tiburon, Calif.

is not called directly into question by these findings, the fact remains that there is not sufficient evidence of deposit quality and quantity presently available upon which to base the major investments required for ocean mining.

Thus it appears that development of marine phosphorite off the California coast is not presently economically feasible and may not be so within the present century. We await the results of pilot operations involving the phosphatic sands off the West Coast of Baja California funded by the government of Mexico. We know of disappointing experiments in dredging phosphorite off the coast of Australia, but at the same time we are privately informed of a "surprisingly" rich deposit of phosphatic mud off the West Coast of South America for the development of which a major oil company has obtained leases and is conducting extensive physical and chemical (beneficiation) studies. We believe that marine phosphorites will come into production in the next decade, but not off the U.S. coast and not in amounts sufficient to significantly affect the world market for land-based phosphates.

In respect to this and other heralded ocean mineral "bonanzas," we would repeat these words of caution: "During the past decade the layman has 'discovered' the ocean. His view of it as an enormous source of food, minerals and energy for future generations has been colored by exaggerated claims based on enthusiasm or commercial interest rather than on scientific inquiry" [10, p. 95].

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THE ECONOMICS OF DEPLETION ALLOWANCE

1. Introduction.

Depletion allowance, in its present form, has been with us since 1926 as Federal legislation, since 1929 as State of California legislation covering corporations, and since 1935 for individuals. In both jurisdictions, tax legislation provides that 27-1/2 percent of the gross value of oil and gas production is free of income taxation, up to a limit of 50 percent of net income from the property. Where the latter is limiting, this means that net income from oil production pays only half the income tax rate that other businesses and individuals are required to pay.

In analyzing some of the economic consequences of depletion allowance, the following points will be covered:

1. Introduction.
2. Depreciation is the normal procedure for a tax-free return of investment.
3. Percentage depletion is in addition to depreciation.
4. Depletion allowance is a subsidy.
5. Subsidies normally create a new set of side-effect problems.
   - A. A subsidy to producers, which causes an increase in output, depresses price and often leads to requests for remedies.
   - B. A subsidy to one industry leads producers of competing products to demand similar subsidies.
6. Subsidies involve costs to society.
   - A. Lower standard of living.
   - B. Weakened national defense capability.
7. Subsidies involve a tax cost.
8. An oil industry reply.
9. Conclusions and recommendations.

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THE ECONOMICS OF DEPLETION ALLOWANCE

Presented before the
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by
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2. Depreciation is the normal procedure for a tax-free return of investment.

As a standard procedure in both accounting and taxation, a taxpayer is entitled to depreciate his initial investment in plant and equipment over a period of years by treating a percentage of such investment as an annual expense until the full original investment is returned. This process is called "depreciation," not "depletion." The petroleum industry is permitted to expense that part of its investment in oil production facilities that classified as intangible drilling costs and lease rentals.[1] By either (1) expensing in the year incurred, or by (2) annual depreciation, initial investments in oil production are fully returned to the taxpayer, free of taxation.[2]

3. Percentage depletion is in addition to depreciation.

The right which oil producers[3] have to take percentage depletion permits a tax-free return of the initial investment in productive wells

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[1] "Intangible drilling costs" include expenditures for labor, fuel, power, materials, supplies, tool rental, and repairs of drilling equipment, in connection with drilling and equipping wells.

[2] Another important means of minimizing tax payments used successfully by the oil industry, although not uniquely by this industry, is to expense intangible drilling costs and lease rentals, thereby reducing income subject to a 48 percent corporate income tax rate or higher personal tax rate, then sell the property for a capital gain. The capital gain is then subject to a maximum tax rate of only 25 percent. In order to close this major loophole, any gains realized on the sale of such property should be taxed as ordinary income to the extent that the cost of the property has been deducted in the past, but still permitting the excess of the sale price over the original cost to be treated as a capital gain. See Secretary of the Treasury, President's Tax Message, Hearings, Committee on Ways and Means, House of Representatives, February, 1963, p. 18.

[3] Other segments of the mineral industry also have a depletion allowance although the rates are below the 27-1/2 percent accorded oil and gas.

many times over.[1] When a taxpayer who owns a productive oil well elects to take percentage depletion, he foregoes the right to expense or depreciate only the lease acquisition cost (if any), and his exploration costs (if any). These two categories of cost are a relatively small part of the total investment in oil well development. Percentage depletion may be taken annually for as long as the well is productive, totally independent of the dollar value of the original investment. Therefore, a productive well may provide a tax-free return of investment ten times, a hundred times, or ten thousand times, in fact, without limit except by 27-1/2 percent of gross and 50 percent of net income, as noted above.

Various devices are also available and are used to minimize the effect of the 50 percent limitation. For example, an integrated oil company may be able to increase its reported income per property by either or both shifting some expenditures from charges against the property to charges against other corporate income, and by inflating the accounting value of its oil at well head. Both devices will increase the reported net income of the oil property and thereby weaken the 50 percent limitation. Further the "mineral production payment" gimmick may be utilized to increase net income for an oil property in a year in which the 50 percent limit would otherwise restrict depletion allowance benefits.[2] The effect is to nullify the 50 percent limitation in many cases.

Percentage depletion has been independent of the initial capital cost since its inception in Federal tax legislation. Rather, it is

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[1]For dry holes, all exploratory and other costs are fully deductible against other gross income of the taxpayer.

[2]For a discussion of the ABC Deal see J. Henry Wilkinson, Jr., "ABC--From A to Z," Texas Law Review, June 1960, 38, 673-724, and Charles O. Galvin, "The 'Ought' and 'Is' of Oil and Gas Taxation," Harvard Law Review, June 1960, 73, 1499-1506.

historically based on a tax-free flow of income equal to the estimated value of the oil property at the point of discovery. The Revenue Act of 1918 granted a 100 percent tax-free income equal to the discovery value of the oil property. The Revenue Act of 1924 reduced the tax-free income flow to 50 percent of the property's net income. Due to the great difficulty of estimating the future output of a producing property and therefore its discovery value, at the point of discovery, the present rule of thumb was established in 1926 permitting 27-1/2 percent of gross income to be returned tax-free. The 27-1/2 percent statutory figure was a political compromise.

The right of tax freedom for up to 50 percent of the net income from a discovered income producing resource is a special privilege not accorded other taxpayers. All businessmen or corporations are permitted a tax free return of investments because income which is reinvested is first subject to taxation as income. Similarly the "discovery" of a movie star does not permit either the "discoverer" or the star a tax-free return of the estimated economic value of the star at the point of discovery. In the case of the depletion allowance, logic would support a tax-free return of the discovery value only if that discovery value itself was initially subject to taxation. But such is not the case.

4. Depletion allowance is a subsidy.

In the absence of any logical basis in either the principles of economics or the principles of taxation, the depletion allowance provision may be examined and appraised as a subsidy.

Spokesmen for the oil industry have argued repeatedly that the depletion allowance is necessary to encourage exploration and development of oil reserves. Yet, economic research has not indicated that the depletion allowance has resulted in a large increase in reserves. Davidson concluded that "in the long-run, percentage depletion does not significantly encourage the allocation of additional real resources to exploring presently unproductive oil lands. The depletion allowance is primarily an ad valorem subsidy to mineral rights owners. A reduction in the depletion allowance will not reduce the incentives to explore undeveloped oil lands."[1] The Davidson position is that most of the subsidy accrues to the oil resource owner in the form of economic rent.

A more recent empirical study is more precise in its conclusions. In its report to the Treasury Department, the CONSAD Research Corporation of Pittsburgh concluded that "percentage depletion is a relatively inefficient method of encouraging exploration and the resultant discovery of new domestic reserves of liquid petroleum."

If the major effect of the tax subsidy is to increase economic rent to owners of oil resources, then the economic consequence is mainly one of income distribution, favoring oil resource owners at the expense of all other taxpayers. On the other hand, if the major effect is to allocate more resources into oil exploration and development, at the expense of investment in other areas and in consumption, then the effect is a probable misallocation of resources. The oil industry, in its appeal

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[1] Paul Davidson, "Policy Problems of the Crude Oil Industry," American Economic Review, March 1963, p. 107.

for a continuation of its subsidy, pleads the national defense justification. This is the common basis used by most claimants of a subsidy. As in most cases, the national defense justification is of doubtful merit. But regardless of its merit, budgetary support for national defense is a function of the Federal Government, not of the state of California.

There is an analytical procedure available in economic analysis to test any industry's claim for a subsidy. A subsidy is merited only in those cases where there are net external benefits (benefits which accrue to society but cannot be captured by the private enterprise that provides the necessary investment). The amount of any justified subsidy is the amount of the net external benefits.

There has never been a demonstration that external benefits are created by oil exploration and development. In any event the only external benefit claimed by the oil industry is national defense and the State of California has no obligation to subsidize any industry for national defense purposes.

The recent Santa Barbara oil spill has, in fact, demonstrated the opposite, that there are significant and serious external costs (costs borne by society and not fully paid for by the private enterprise which caused them) due to oil explration and development. If there are net external costs rather than benefits, then the proper public policy calls for a special tax (not a subsidy) to be levied on the oil industry equal in amount to the net external costs.

5. Subsidies normally create a new set of side-effect problems.

A. If the depletion allowance subsidy in fact has stimulated oil development and production, then one inevitable effect of an increased supply of oil is lower crude oil prices. But owners of crude oil producing lands prefer high prices to low prices and may be led to seek relief through (1) a system of prorationing whereby production limitations are placed on producers, and (2) a system of import quotas to reduce the supply of competing oil from foreign sources. In fact, both relief measures have been sought and granted.

B. Subsidies to one industry commonly favor that industry at the expense of close substitute products and lead producers of such substitute products to demand compensating subsidies. This, in fact, has also happened. The percentage depletion rate on oil shale amounts to 15 percent of the gross value of oil shale after it is mined and crushed prior to retorting. This is equivalent to about 7.5 percent depletion on <u>oil</u> produced from shale. "Spokesmen for oil shale interests have argued that the allowable percentage depletion should be 27-1/2 percent (the same as for petroleum) and that it should be based on the value of the <u>shale oil</u> after its extraction from the oil shale."[1] Oil from shale must compete with crude oil, hence an equity question arises. Reducing both to zero depletion rates would be a logical solution.

Similarly, petroleum products may be produced from coal and from tar sands. Equity would seem to require similar subsidies to these

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[1]U.S. Department of the Interior, <u>Prospects for Oil Shale Development</u>, May 1968, p. 109.

petroleum sources. Also, nuclear power competes with power generated from oil. The equity question arises again. A free enterprise solution is to subsidize none, except when supported by clear evidence of net external benefits, and there has been no evidence submitted to date.

6. Subsidies involve costs to society.

When an unjustified system of subsidies is introduced to modify the pattern of resource allocation provided by a free price system, resource misallocation follows. The economic consequence of resource misallocation is (A) a lower standard of living, relative to what might have been without interference with the free prices mechanism, and (B) weakened (not strengthened as claimed by the oil industry) national defense capability since output of the economy is below its maximum level of efficiency. The strength of a nation is rooted in its productive ability.

We have no estimate of the social cost to California citizens due to depletion allowance. However, we do have an estimate of the social cost to the United State due to depletion allowance, prorationing, and import quotas on oil. Professor Adelman has estimated that, based on 1961 conditions, "the annual charge of this whole system of organized waste, including the import controls needed to insulate it from foreign competition ... is just over $4 billion."[1]

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[1] M. A. Adelman, "Efficiency in Resource Use in Crude Petroleum," Southern Economic Journal, October 1964, p. 105.

7. Subsidies involve a tax cost.

A tax subsidy involves a tax cost. One group of taxpayers is granted a privileged position. If total revenue needs of the State of California are constant with or without the tax subsidy, as is probably the case, then other taxpayers must pay higher taxes to compensate for privileges granted to the favored group. The annual tax cost in the State of California can be estmated for oil alone. In 1966 crude oil production in California amounted to 345 million barrels. Assuming an average value at wellhead of $3 per barrel, the gross value of California crude production was $1,035 million. One recognized student of oil industry taxation estimated that the net benefit of percentage depletion allowance, over and above cost depletion, amounts to about 20 percent of the gross value of oil production.[1] Using this estimate, we find that the tax cost to other California taxpayers of depletion allowance for the oil industry in the year 1966 was $207 million. This estimate should be treated as a rough approximation only.

The effective corporate income tax rate reflects not only the depletion allowance, which reduces the 48 percent corporate tax rate by approximately half, but other tax gimmicks as well, which reduce the effective rate toward zero. The net result is that over the five year period from 1962 through 1966, the 22 largest U.S. oil companies had an effective Federal

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[1] Stephen L. McDonald, "Percentage Depletion and the Allocation of Resources: The Case of Oil and Gas," National Tax Journal, December 1961, p. 329.

income tax rate of slightly more than 6 percent.[1] This is considerably below the 48 percent tax rate that other corporations are required to pay. The Standard Oil Company of California had a tax rate of only 3.8 percent, while Union Oil Company of California paid Federal corporate income taxes at 14.9 percent of net income. Union's relatively high tax rate (relative to other oil companies) is due to its minor position as an international oil company. Thus it receives only minor benefit from U.S. tax foregiveness equal to the sum of oil royalties paid to foreign governments.

8. An Oil Industry Reply.

Oil industry spokesmen have defended their various subsidies with the question, "If we receive all the subsidies which our critics allege, why is our rate of return on invested capital not substantially higher than other nonsubsidized industries?" The answer to this question is that a subsidy will raise the profit rate at the point in time at which it is conferred. Its effects, however, are eroded away with time as producers react to their more profitable situation by expanding investments into otherwise submarginal areas. This expansion leads to a decline in the rate of return toward a normal yield and to resource misallocation as well. This expected decline in rate of return to normal has, in fact, occurred. In 1968 the after-tax rate of return on equity for the oil industry was 11.8 percent, compared to 11.7 percent for all industry.[2]

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[1] Congressional Record, U.S. Senate, August 28, 1967, p. S-12309.

[2] "The 500 Largest Industrials," Fortune, May 15, 1969, p. 185.

9. Conclusions and Recommendation.

Given the existing rights of mineral developers to fully expense or depreciate all costs of exploration and development, there is no economic basis for percentage depletion allowance where the latter permits such developers to recover their investment tax free again and again.

While the oil industry has claimed a national defense basis for a tax subsidy, this has never been demonstrated, and even if granted, a subsidy for national defense is a function of the Federal Government, not of a state government.

A subsidy that is not justified by a showing of net external benefits, produces resource misallocation, which in turn lowers our standard of living and weakens our national defense capability. The estimated cost to the nation, due to oil industry subsidies, is about $4 billion annually. The annual tax burden to California state taxpayers (not including Federal taxes) for support of the State's depletion allowance is estimated at $207 million. The benefits appear to be negative.

Accordingly I urge that depletion allowance be reduced to zero.

GOVERNMENTAL INTERVENTION IN THE MARKET MECHANISM

HEARINGS

BEFORE THE

SUBCOMMITTEE ON ANTITRUST AND MONOPOLY

OF THE

COMMITTEE ON THE JUDICIARY
UNITED STATES SENATE

NINETY-FIRST CONGRESS

FIRST SESSION

S. RES. 40

THE PETROLEUM INDUSTRY

PART 1

Economists' Views

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made sales at these prices included Esso International, Mobil Sales, British Petroleum Trading, Shell International Petroleum, Chevron, which is, I understand, Standard Oil of California, Texaco, and Gulf Oil Corp.

Senator HART. Without objection they will be received.

BRAZILIAN EMBASSY,
Washington, D.C., October 4, 1968.

Subject. Information on Brazilian oil imports.

Dr. JOHN BLAIR,
Chief Economist
Anti-Trust Subcommittee
Senate Office, Room 414.

DEAR DR. BLAIR: Referring to your request above mentioned, we have the pleasure to enclose some information on the matter, which we hope will be of use to you.

Yours truly,

PEDRO PAULA PINTO ASSUMPÇÃO,
Second Secretary.

IMPORTS OF PETROLEUM MADE BY PETROBRAS DURING THE PERIOD 1964-66

Origem	°API (cruzeiro)	Modalidade f.o.b. preco f.o.b. (US $/b)			Modalidade C and F preco C and F (US $/b)			Fornecedor
		1964	1965	1966	1964	1965	1966	
Venezuela	35-40	1.78	1.75	1.75				Compañia Shell de Venezuela, Venezuelan Sun Oil Co., and Atlantic Richfield Co.
	10-15	1.51	1.47	1.37				Texaco Overseas Petroleum Co., Richmond Exploration Co., Chevron Oil Trading Co., Sinclair International, Gulf Oil Corp., and Esso International Inc.
Oriente Médio (Arabia Saudita, Iraque, Kuwait).	31-38		1.30	1.30	1.95	1.91	1.82	Esso International Inc., Mobil Sales, Total International, British Petroleum Trading, Ltd. Shell International Petroleum Co. Chevron Oil Trading Co., Texaco Overseas Petroleum Co. and Gulf Oil Corp.
Africa (Angella, Nigéria).	30-44	1.80		1.65		2.20	2.15	Shell International Petroleum Co., Gulf Oil Corp., and Société Nationale des Pétroles D'Aquitaine (SNPA).
U.R.S.S.	32				2.10	1.95	1.87	V.O Sojuznefteexport.

Dr. BLAIR. The last two exhibits are staff memoranda which have been prepared respectively by Dr. Browne, and Dr. Measday, the former on the cost of tanker transportation which is an exposition of the manner in which rates for tankers are arrived at; and the latter is a history of Federal cooperation with the petroleum industry.

Mr. Chairman, I would like to have those entered in the record.

Senator HART. These will be received without objection.

(The two memoranda may be found in the appendix, pp. 578 and 599.)

Dr. BLAIR. Thank you, sir.

Senator HART. As I said when you concluded your testimony, Mr. Newton, we are in your debt for the wealth of facts that you have put into this record with respect to the basic figures that we will need as we go forward. We are very grateful to you.

Mr. NEWTON. Thank you.

Senator HART. The arrangements have been made and we are grateful to Professor Mead for his willingness to stay over. We will adjourn, to resume at 10 tomorrow morning in this room. At least at the opening of that session Senator Kennedy, of Massachusetts, will preside.

(Whereupon, at 4:10 p.m., a recess was taken until the following day, Wednesday, March 12, 1969, at 10 a.m.)

WEDNESDAY, MARCH 12, 1969

The subcommittee met, pursuant to recess, at 10 a.m., in Room 1318, New Senate Office Building, Senator Edward M. Kennedy presiding.

Present: Senators Kennedy and Fong.

Also present: S. Jerry Cohen, staff director and chief counsel; Dr. John M. Blair, chief economist; Horace L. Flurry, assistant staff director and chief counsel; Peter N. Chumbris, chief counsel for the minority; Kirkley Coulter, economist for the minority; Gladys E. Montier, clerk; and Patricia Bario, editorial director.

Senator KENNEDY. The subcommittee will come to order.

Our first and only witness today is Prof. Walter J. Mead of the Department of Economics, University of California, Santa Barbara. Professor Mead, whose previous testimony appears in part 4 of the subcommittee hearing on economic concentration, is particularly noted for his studies in the field of competition and conservation. Currently he is preparing a paper on the welfare costs of oil import quotas which will appear this year as part of a symposium in the Natural Resources Journal. In addition, he was a subcontractor on the Public Land Law Review Commission study of the Outer Continental Shelf. In this study he was responsible for all the economic analysis; the major mineral discussed was oil. He is currently president of the Western Economic Association.

Professor Mead, I want to welcome you to the subcommittee. I have had a chance in the past to have an exchange of letters and correspondence with you, and have reviewed some of your previous writings, and I know you bring to the subcommittee and to this subject a broad background, experience, and concern, and I know we will benefit greatly from your observations and comments. I want to say how pleased we are to have you here this morning.

You may proceed.

STATEMENT OF PROF. WALTER J. MEAD, PROFESSOR OF ECONOMICS, UNIVERSITY OF CALIFORNIA, SANTA BARBARA

Dr. MEAD. Thank you. It is nice to be back here.

I would like to read my statement.

Senator KENNEDY. Fine.

Dr. MEAD. It seems entirely appropriate for the Senate Subcommittee on Antitrust and Monopoly to conduct hearings on governmental intervention into the market mechanism of the petroleum industry. There is, in fact, a system of tax subsidies to stimulate petroleum resource discovery and production, together with production and marketing controls designed to restrict supply and thereby maintain oil prices substantially above competitive levels. Import quotas have been instituted in order to insulate the domestic oil market from the challenge of foreign competition. Given this barrier to free entry into the U.S. market, the price of crude oil in the United States is approximately double the free market world price. In the first half of 1968 the Japanese Government purchased approximately 2.3 million barrels per day of largely Middle Eastern crude at prices averaging $1.42 per barrel. This oil had an average API gravity rating of 32.3 degrees. In contrast crude prices in the United States for similar gravity ratings have been about $3 per barrel.

The largest Japanese purchases were of Iranian heavy crude oil at a price of $1.35 per barrel. Table 1 shows that this oil might be transported to the East Coast markets of the United States and would have a delivered price of about $2.10 per barrel before payment of tariff. U.S. crude oil, having the same gravity rating, can be purchased at a Texas Gulf port for $3.12 per barrel and delivered to the East Coast at a delivered price of about $3.42 per barrel. This delivered price difference of $1.32 per barrel before tariff and $1.22 after the tariff could not exist except for the protection afforded by the tariff and import quota.[1]

TABLE 1.—*Comparison of U.S. and world prices of crude oil*

Middle East crude oil:	
Price of Iranian heavy crude 31.0° average gravity FOB	$1.35
Transportation cost U.S. East Coast port	.75
Total delivered price before tariff	2.10
U.S. tariff 10.5¢ per barrel	.10
Total delivered price after tariff	2.20
U.S. crude oil:	
Price of Texas crude 31–31.9° gravity, Refugio, Tex	3.12
Transportation cost to East Coast port	.30
	3.42

Further evidence supporting the price differential shown in table 1 is provided by the fact that import "tickets" have in recent years had a market value of about $1.25 per barrel. The value of a ticket to import one barrel of crude oil into PAD districts I–IV (east of the Rocky Mountains) has recently and probably temporarily fallen from $1.25 per barrel to about 75 cents per barrel.[2] This is the result of substantially higher freight rates due in turn to the Suez Canal closure and to a shortage of large oil tankers.

A recent U.S. Department of Interior study conservatively estimated that if import quotas were removed the impact of world competition would cause the American price of crude oil east of the Rocky Mountains to decline approximately 95 cents per barrel.[3]

The relatively high U.S. price of crude oil is the result of a complex system of tax subsidies and production restrictions imposed on behalf of the domestic oil industry. Import quotas are simply a capstone

[1] All should be warned that oil price and cost data are extremely complicated. Free market prices are scarce and may involve tax conditions, side payments, trades, as well as quality and geographical differences that are not clear.

[2] Oil and Gas Journal, Dec. 2, 1968, pp. 25–26.

[3] Office of Cordell Moore, Assistant Secretary of the Interior, "Cost of the Oil Import Program to the American Economy," Jan. 16, 1969, p. 1. Since this study was authorized and issued by the Department administering the oil import program, any bias would be expected to minimize the cost to the economy by minimizing the spread between United States and world crude prices.

which the system requires in order to be insulated from foreign competition.

The purpose of this paper is to review the system of oil industry subsidies in total. I understand that others will concentrate on detailed analysis of the component parts of the subsidy system.

I. *Percentage depletion allowance.*—Percentage depletion must be distinguished from the conventional right to a tax-free recovery of a previous investment. Rather, it is historically based on a tax-free flow of income equal to the estimated value of the oil property at the point of discovery. The Revenue Act of 1918 granted a 100-percent tax-free income equal to the discovery value of the oil property, independent of discovery costs. The Revenue Act of 1924 reduced the tax-free income flow to a maximum of 50 percent of the property's net income. In 1926, the present rule of thumb was established permitting 27½ percent of the gross income (not net), from an oil property to be free of tax, up to a limit of 50 percent of the net income from that property. Thus, where the full value of the depletion allowance is used, the effect is to reduce the Federal income tax rate on oil income by half.

While percentage depletion allowance is based historically on discovery value rather than a tax free return of an initial investment, the latter is also permitted for important items of exploration and development cost. The present law permits depreciation of all tangible equipment costs for producing wells. In addition, lease rentals and all intangible drilling costs may be expensed as incurred including expenditures for labor, fuel, power, materials, supplies, tool rental and repairs of drilling equipment in connection with drilling and equipping wells. Therefore, a taxpayer electing to take percentage depletion instead of cost depletion not only receives up to 50 percent of the property's net income free of tax, but receives a tax-free return of all of his initial investment except his lease acquisition costs and his exploration expenses. For productive wells, he may recover these costs only by electing to take cost depletion in lieu of percentage depletion. For nonproductive wells, even these may be expensed when the property is abandoned.

Various devices are also available and are used to minimize the effect of the 50 percent limitation. For example, an integrated oil company may be able to increase its reported income per property by either or both shifting from expenditures from charges against the property to charges against other corporate income, and by inflating the accounting value of its oil at well head. Both devices will increase the reported net income of the oil property and thereby weaken the 50 percent limitation. Further the "ABC deal" involving production payments may be utilized to increase net income for an oil property in a year in which the 50 percent limit would otherwise restrict depletion allowance benefits.[4]

Percentage depletion allowance benefits were introduced during and following World War I as a tax subsidy to encourage oil exploration and development. Since investors make investment decisions on the basis of their anticipated after-tax rates of return, and since the depletion allowance permits a sizable reduction in corporate or personal

[4] For a discussion of the ABC deal see J. Henry Wilkinson Jr., "ABC—From A to Z," Texas Law Review, June 1960, 38, 673–724, and Charles O. Galvin, "The 'Ought' and 'Is' of Oil and Gas Taxation," Harvard Law Review, June 1960, 73, 1499–1506.

income taxes, we should expect an increased flow of capital into oil exploration and production at the expense of other investment alternatives. This should be followed in time by expanded output (a shift of the short-run supply curve to the right.)[5] As a further consequence, the price of oil would be reduced below levels which would otherwise prevail.

II. *Market-demand prorationing.*—Price depressing effects of the percentage depletion allowance tax subsidy were accentuated, probably fortuitously, by the discovery of the East Texas oil field in 1930. This discovery substantially increased the supply of oil at a time when demand was declining. Consequent sharp declines in the price of oil, together with unrestricted drilling and production from jointly owned oil properties, culminated in the passage of prorationing laws in the leading oil producing States.[6]

Prorationing may be defined as "the rules and procedures by which a regulatory agency determines the total crude oil production from a State and allocates the total among the various reservoirs and to the producers in each reservoir."[7] Prorationing consists of two parts: (1) MER (maximum efficient rate) prorationing and (2) market-demand prorationing.

(1) MER prorationing attempts to calculate the maximum efficient rate of production, presumably on the basis of physical characteristics of the reservoir, and production quotas are then prorated (rationed) among the producers involved. These permitted levels of production are called "allowables." The need for MER-type prorationing follows from the fact of common reservoir ownership. In the absence of unitization and MER-type prorationing, each owner of the common property, oil, in a given reservoir would compete to recover at least his full share before it was drained away by other owners .The result would be vast over-investment and inefficient utilization of the oil reservoir. While the need for MER-type prorationing is granted, the only justification for market-demand prorationing is from the resource owner's point of view, who presumably would prefer high prices for his crude rather than low prices.[8]

[5] The assumption is made that the supply of uncommitted oil leases is not perfectly inelastic. We have no information on the extent of the current increase in production due to this tax subsidy. It is obvious that the tax subsidy does not increase oil in the ground, but presumably causes it to be produced earlier rather than later. For a discussion of the resource misallocation effects of the percentage depletion allowance provision see Arnold C. Harberger, "The Taxation of Mineral Industries," Federal Tax Policy for Economic Growth and Stability, a Compendium of Papers presented to the Joint Committee on the Economic Report, 84th Cong., first sess. (1955); Stephen L. McDonald, "Federal Tax Treatment of Income From Oil and Gas." Washington, D.C.: The Brookings Institution, 1963, especially ch. 3; and A. E. Kahn, "The Depletion Allowance in the Context of Cartelization," American Economic Review, June 1964, 54, p. 295.

[6] The first State to undertake prorationing was Oklahoma. The Oklahoma Corporation Commission instituted prorationing in September 1928. Texas followed with its first attempt at statewide prorationing in 1930. On August 27, 1935, Congress approved the "Interstate Compact To Conserve Oil and Gas" and the Interstate Oil Compact Commission was created on Sept. 12, 1935. The purpose of the compact was "to conserve oil and gas by the prevention of physical waste thereof from any cause."

[7] Wallace F. Lovejoy and Paul T. Homan, "Economic Aspects of Oil Conservation Regulation." Baltimore: The Johns Hopkins Press, 1967, p. 127.

[8] While granting the need for MER-type prorationing, the manner in which it is currently administered has been subject to widespread criticism. The calculation itself has been shown to be faulty from the economic analysis point of view. Further, the most inefficient wells are frequently exempt from prorationing (particularly market-demand prorationing in Texas), while the most productive wells are forced to curtail output and thereby to operate inefficiently. Hardwicke has estimated that the economic waste due to unneeded wells in Texas alone amounts to more than $100,000,000 a year. See Robert D. Hardwicke, "Oil Well Spacing Regulation and Protection of Property Rights in Texas," Texas Law Review, 1952, 3, p. 31. For an extensive analysis of economic inefficiency in prorationing procedures see Lovejoy and Homan, op. cit., Chaps. 4–7.

(2) Under market-demand prorationing the State regulatory agency determines and restricts production to a level calculated to equal the quantity demanded at the prevailing price. This determination is made on a monthly basis. Market-demand prorationing normally further restricts production below the maximum efficient rate of production. For example, the Texas Railroad Commission has determined that for the month of February 1969, nonexempt operators in Texas may produce at only 42.8 percent of their allowable production. Thus, while the MER allowable is theoretically related to production efficiency for a given reservoir, market-demand prorationing is related to the quantity that the market will absorb at a "desired price" of crude oil. The desired price is maintained by restricting the level of production. Article V of the Interstate Oil Compact specifically denies any price-fixing intent. Article V states:

> It is not the purpose of this Compact to authorize the States joining herein to limit the production of oil or gas for the purpose of stabilizing or fixing the price thereof, or to create or perpetuate monopoly.

However, unless the law of demand has been repealed for oil, larger quantities will be demanded at lower prices, and production restrictions will generate higher prices.

The price effect of market-demand prorationing can be clearly seen in figure 1.

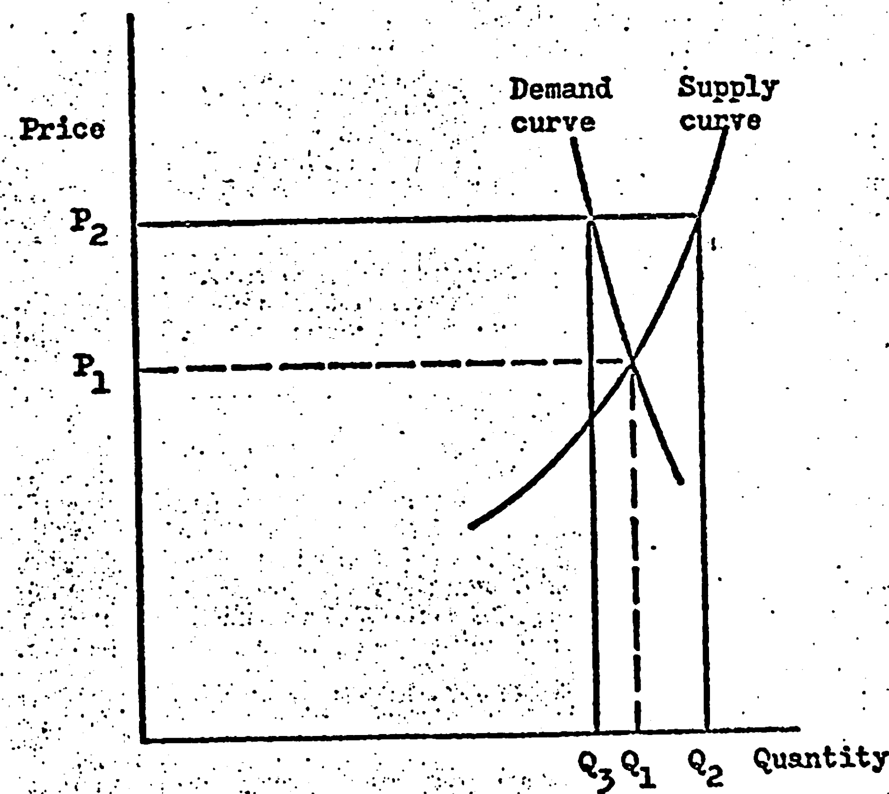

Figure 1--. Illustration of "excess capacity"

Dr. MEAD. At P_1, the quantity demanded equals the quantity supplied at Q_1. This is the normal situation in a free price market. Where a higher price is desired, for example, P_2, the quantity demanded is only Q_3. But at this more attractive price, from the seller's point of view, Q_2 will be supplied. The excess of quantity supplied over quantity demanded (the distance Q_3 to Q_2) would force the price downward toward P_1 in a free market system. In order to obtain the desired higher price (P_2) producers must submit to production controls. Specifically, production must be limited to Q_3 since this is the quantity which the market will demand at P_2, the desired price. The function of market-demand prorationing is to restrict output to some level such as Q_3, since this is the quantity which the market will absorb at the desired price. Market-demand prorationing at less than 100 percent of the maximum efficient rate of production creates a situation of excess capacity with its consequent social cost of over-investment.[9] Administrators of state prorationing systems have maintained the judicious fiction that the objective of prorationing is the prevention of waste. One official, when questioned about the price effect of prorationing, replied: "We have nothing to do with price. We are forbidden to consider economics; purely physical waste. I know nothing about price." [10]

As indicated in section I above, percentage depletion allowance, as a significant tax subsidy, has the effect of shifting the supply curve for oil to the right and, in the long run, depressing oil prices. The 27½ percent depletion allowance rate has now been in effect for 43 years and presumably would have brought about an expansion of oil production and depressed prices to the point where the after-tax rate of return on oil exploration and development investments would be only normal. The price depressing effect, however, has been prevented by market-demand prorationing. In effect, one interference with the market mechanism (depletion allowance), has stimulated production and brought forth a second interference with the market mechanism (prorationing) introducing production controls.

Market-demand prorationing, however, rests on a precarious foundation. The leading oil-producing States, excepting California and Wyoming, have market-demand prorationing controls. Lovejoy and Homan found that the States having market-demand prorationing account for 75 percent of U.S. crude production.[11] These States bear the burden of price fixing. Their dilemma is that of a dominant firm (or group of firms), that chooses to behave as a monopolist in an oligopolistic industry. They must restrict output in order to maintain the desired price while producers in nonmarket-demand States are free to maximize their own profit given the artificially maintained high price. As recently as mid-1966 Oklahoma, the fourth largest oil-producing State, restricted production to 38 percent of the maximum efficient rate. For February 1969 the permitted rate was raised to 90 percent.

[9] While one may dispute the exact degree of supply and demand elasticity (the slope of the supply and demand curves) and the deviation of P_2 (the present price of American crude) from the P_1 (the price which would prevail in a free market), Figure 1 describes the essence of the market demand prorationing problem. The demand curve illustrated in Figure 1 is shown to be relatively inelastic as is generally assumed. See Interstate Oil Compact Commission, a Study of Conservation of Oil and Gas in the United States (1964), p. 122.

[10] Testimony of Ernest O. Thompson, member of Texas Railroad Commission, at the hearings of the Committee on Interstate and Foreign Commerce, House of Representatives, 85th Cong., 1st sess. (1957), quoted in Lovejoy and Homan, p. 210.

[11] Op. cit., p. 129.

Effective for March 1969, the Oklahoma Corporation Commission announced that production at 100 percent of the maximum efficient rate would be permitted. Thus, if we may assume that Oklahoma's MER-type prorationing involves no price-fixing features, then Oklahoma has, in effect, passed the burden of price stabilization to other market-demand States.

III. *Oil import quotas.*—Under conditions of free trade, the ability of an oil price conspiracy to raise domestic prices above the competitive equilibrium level is limited by the prevailing world price plus freight charges to the United States. If the domestic producers desires a price in excess of this premium then they must obtain import barriers usually in the form of tariffs or import quotas. The American oil industry has obtained both. The current tariff on crude oil is 10½ cents per barrel. This rate has been in effect since 1943.

On July 29, 1957, President Eisenhower asked oil importers operating east of the Rocky Mountains to voluntarily reduce their crude oil imports to 10 percent below their average for 1954–56; that is, to about 1 million barrels per day. Under strong pressure from the Independent Petroleum Association of America, supported in turn by the National Coal Association, President Eisenhower on March 10, 1959, ordered mandatory quotas on imports of crude oil, gasoline, and other finished petroleum products. On April 30 the order was amended to exempt from the mandatory limits oil shipped by overland transportation from Canada and Mexico. Imports into districts I to IV (the area east of the Rocky Mountains), are limited to 12.2 percent of estimated domestic production in these districts, less the exempted production from Canada and Mexico. Imports into district V (the area west of the Rocky Mountains), were limited to the difference between (1) the sum of district V domestic supply and exempt imports from Canada and Mexico and (2) total demand (at the desired price) in that district as estimated by the Bureau of Mines.

Given the relatively high U.S. price for crude oil, resulting in part from market-demand prorationing, U.S. oil exports declined and imports into the United States increased sharply. The trends from 1939 through 1968 are shown in figure 2. Figure 3 shows the relation of crude oil imports to the domestic demand for all oil products from 1939 through 1968.

We find that imports increased from 2.7 percent of total demand in 1939, to 11.6 percent in 1957 when voluntary import restrictions were imposed. From 1957 to date the ratio of imports to domestic demand has declined under the impact of import quotas. Figure 2 shows, however, that the absolute level of imports increased after the imposition of controls, but at a lower growth rate.

Import restrictions have had the effect of producing a gap between American and world crude prices amounting to approximately $1.32 per barrel, in excess of transportation charges. Thus, import quotas and the tariff are part of the system of subsidies received by the oil industry. Market-demand prorationing, as a price-fixing device, would have limited effectiveness in the absence of import restrictions.

IV. *U.S. Federal income tax credit for foreign royalties paid.*—Another major subsidy is available only to the international oil companies. In the United States when oil companies pay royalties to landowners, whether Government or private, such royalty costs are treated as nor-

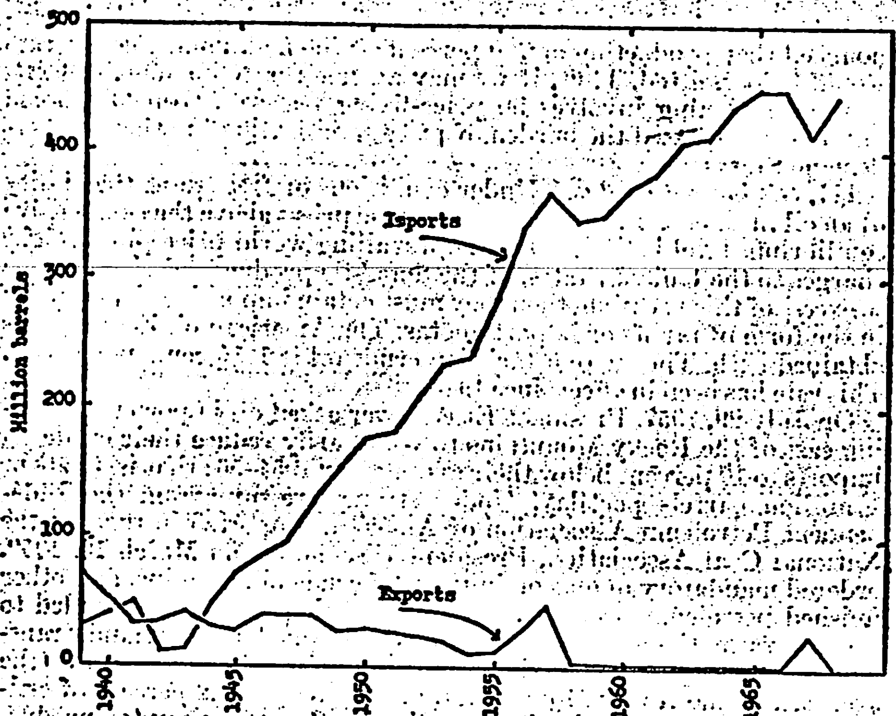

Figure 2—. Crude oil exports and imports.

Source: U. S. Department of Commerce, Survey of Current Business.

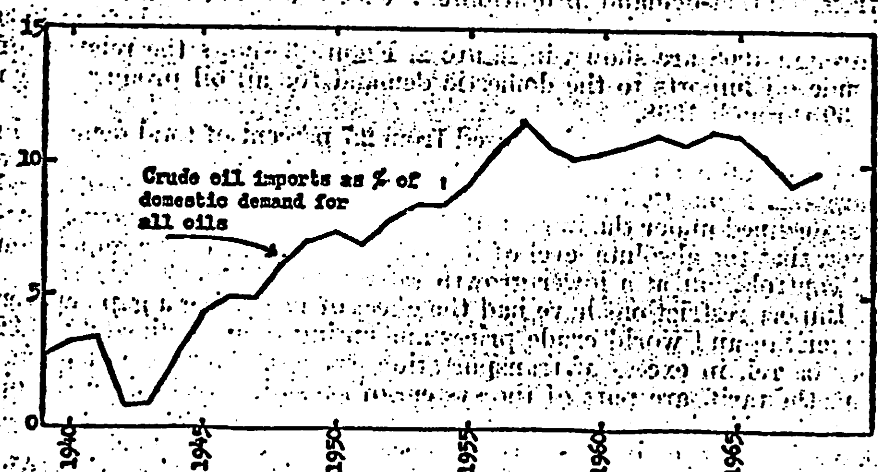

Figure 3— Crude oil imports as % of domestic demand for all oils.

Source: U. S. Department of Commerce, Survey of Current Business.

mal expenses of doing business. But when certain legal formalities are observed, royalties paid to foreign governments may be classified as foreign taxes and are treated in lieu of U.S. corporate income taxes. This tax treatment means that such foreign royalty expenses involve a zero aftertax cost to the American oil firm. In effect, the American Government pays about 100 percent of the foreign royalty charges.

The consequences are at least twofold. First, foreign oil development is stimulated at the expense of development in the United States. It should be noted here that this subsidy runs counter to the stated intent of depletion allowance—to stimulate domestic oil exploration and development. Second, U.S. income taxes paid by American oil companies with international operations already reduced by the percentage depletion allowance and other tax favors, are further drastically reduced. The record shows that Standard Oil Co. of New Jersey, the largest U.S. oil company, had an effective Federal income tax rate of only 3.8 percent over the 5-year period. 1962–66. The 22 largest U.S. oil companies had an effective Federal income tax rate averaging slightly more than 6 percent.[12]

Senator KENNEDY. As I understand, what you are suggesting here is that one of the principal justifications for the whole depletion allowance, and certain other tax advantages, was to stimulate the discovery and the production of oil reserves here in the United States, so the justification for that, at least the stated purpose for that as I understand it, is primarily for national security reasons?

Dr. MEAD. Yes. This was the justification.

Senator KENNEDY. What you are additionally suggesting is that because of the particular tax advantages that are provided to the major oil companies, in terms of tax credits and depletion allowances, we are actually encouraging more of the research, more of the discovery efforts, in the Middle East and in these other foreign fields?

Dr. MEAD. That is correct.

Senator KENNEDY. So, actually, a program justified in terms of stimulating the domestic oil industry is, because of other Government policies, actually stimulating foreign exploration and development.

Dr. MEAD. The credit for foreign taxes in part nullifies the depletion allowance, or the effects of depletion allowance. It does nothing to reduce that very favorable tax rate and it still enables certain people to have very high after-tax income in oil, but if the purpose of depletion allowance was to stimulate domestic production, that purpose is partly nullified by the second tax gimmick, that of U.S. credit for foreign taxes paid.

Senator KENNEDY. Can you support that with some evidence? I mean, can you show that actually the efforts which are being made by the majors or smaller companies in the field of exploration are of a limited nature, that the principal kinds of efforts being made by the majors are in the foreign field?

Dr. MEAD. Yes. It would be easy to present figures to show this. It would consist of the very high level of foreign oil exploration and development investment in recent years, and that presumably would reduce the funds available for domestic exploration and development.

Senator KENNEDY. I suppose that you relate those figures to a significant extent to this foreign tax credit?

[12] Congressional Record, Senate, Aug. 28, 1967, p. 24310.

Dr. MEAD. Yes; certainly.

Senator KENNEDY. Are there other sound economic reasons for it that would be pressed by the industries themselves? What would their explanations be in response to that? Would they say that there are greater known oil reserves in these other parts of the world?

Dr. MEAD. Well, if that is the response, then, of course, there would be no further need for the domestic depletion allowance. So they would not make that point. I have asked them this question, and the response I get is that we after all are paying taxes abroad and you cannot expect us to pay taxes on taxes. The gimmick is these are royalties, not taxes.

Senator KENNEDY. I am not sure whether you were here yesterday.

Dr. MEAD. I was.

Senator KENNEDY. But we were trying to at least develop that point and I am sure you have at least an opinion on that question. It would appear to me that with the extraordinarily high payments in relation to cost, the payments should be treated as royalties, not taxes.

Dr. MEAD. That is right.

Senator KENNEDY. Would you talk on that point just a little further?

Dr. MEAD. Yes. The thing called the foreign tax is exactly the same as a royalty paid in this country. On certain Federal leases, for example, the royalty is 16⅔ percent. Now, that royalty in this country is treated as a normal expense of doing business. It should be treated exactly the same way abroad but it is not. It is classified as a tax. It is exactly the same payment.

Now, one of the problems that comes out of this is, as you can readily understand, there is very little resistance on the part of an American oil company to pressure from abroad to increase that royalty, the payments to a foreign kingdom. Why is there no resistance? Because the U.S. Government pays it. So, the American oil company does not want to fight to keep that royalty down. It does not cost them anything. The Federal Government pays the whole business.

Senator KENNEDY. The taxpayers pay it.

Dr. MEAD. That is the U.S. taxpayer.

Senator KENNEDY. Now, just for my own information, and I am quite in the dark about tax systems of these foreign countries, do they impose this type of tax on other corporate entities within their countries or is this a special kind of a tax which is imposed by these respective countries? As I understand it, this is peculiar to the oil industry which would again suggest and support your arguments that in effect, it really is a royalty and not a tax.

Dr. MEAD. Yes. This is also my understanding. However, I am not an expert in that area and I cannot testify with any finality.

Senator KENNEDY. You may proceed.

Dr. MEAD. *V. Resource Misallocation.*—The net effect of the entire subsidy system available to the oil industry is overinvestment in oil exploration and production, and consequent misallocation of the Nation's resources. We are developing resources at social costs of about $3.42 per barrel that have a social value of about $2.10 per barrel. Resource misallocation in turn results in a lower standard of living than is otherwise available to this Nation. To the extent that we do not wisely use our limited natural resources, our longrun ability to defend ourselves is weakened.

Senator KENNEDY. I am sorry, Professor. We will have to have a 5-minute recess. Then, we will resume.

(A recess was taken.)

Senator KENNEDY. The subcommittee will come to order.

If you will be kind enough to proceed, Professor Mead.

Dr. MEAD. On the resource misallocation point, I simply make the point that we are recovering resources that have a cost greater than their value, and this, in fact, penalizes our national defense rather than strengthens it.

This next paragraph simply reaffirms Adelman's point that he made yesterday. The welfare cost of the system of organized waste, as he calls it, is about $4 billion a year and I agree with Dr. Blair's comments following that, that it has now grown beyond $4 billion a year. If national defense is the justification for this system of subsidies, I suspect we can achieve such defense benefits at a lower price than $4-plus billion a year.

Senator KENNEDY. Are you suggesting there that we could devise other kinds of procedures to insure that there would be available a wartime oil capability? It is your own belief that we could devise a system which would not be as costly in terms of the consuming public which is paying these subsidies now. Is that the point?

Dr. MEAD. That is my view. This is not the subject of my paper and this should be developed separately, but to outline my thoughts on the subject, they go like this. Any profit-maximizing oil company is not going to permit their company's reserves to fall to zero. Any company is going to want to maintain 5, 6, 7—I do not know how many—years of reserves, completely absent any kind of import quotas and prorationing.

Secondly, in the event of a war, our foreign sources are not going to decline to zero. We know that.

Third, we have vast oil reserves in the form of oil shale, and to quote just one figure on that, if you look at the oil shale in Colorado and count only the richest, that having more than 25 gallons per ton, there are 600 billion barrels available. Now, that is an awful lot of oil.

Senator KENNEDY. I realize there are engineering problems and extracting problems, but in terms of that figure, 600 billion barrels, how would it compare to our projected use of oil over the next 10 years?

Dr. MEAD. Offhand I cannot answer, but in this study of oil shale, there is an answer to the question. I can perhaps dig it out later for you.

Senator KENNEDY. Well, I mean, is it—are we talking about 10 years or are we talking about 100 years?

Dr. MEAD. This is 1,000 years of supply of oil at current production from oil shale.

Senator KENNEDY. In the United States?

Dr. MEAD. Yes. Here, let me give you another figure. If we take the oil——

Senator KENNEDY. As I understand from staff, we expect to use about 50 billion barrels over the next 10 years. Does that sound like a reasonable figure?

Dr. MEAD. That sounds about right.

Senator KENNEDY. And this 600 billion barrels in this Colorado——

Dr. MEAD. That is only the richest oil.

Senator KENNEDY. Let me ask you one other question that concerns me. Do you find problems in justifying the argument on the basis of national security? I would think if we are interested in the question of national security we would be importing more oil and setting aside the reserves that we have.

Dr. MEAD. Precisely. So, in effect, this argument——

Senator KENNEDY. Obviously, as with any other industry which is going to be essential for national security, we ought to be thinking in terms of how we are going to keep them in a constant state of readiness.

Dr. MEAD. Precisely.

Senator KENNEDY. And it is your belief that the economics of that would be dramatically less than the $4 billion we are paying a year in terms of keeping this industry supposedly ready for national security.

Dr. MEAD. There are cheaper ways to do it, but the oil import system simply sacrifices the future for the present.

Senator KENNEDY. Do you believe there are more efficient ways to do it?

Dr. MEAD. I certainly do, but I have not made the point in this paper. That is another subject.

Senator KENNEDY. Thank you. You may proceed.

Dr. MEAD. The effect of market-demand prorationing and import quotas is to substantially raise the domestic price of crude oil and oil products. The effect of favored tax treatment is to reduce tax costs for oil companies relative to firms in other industries. These measures taken together substantially raise the expected aftertax profit rates on oil industry exploration and development investments in what would otherwise be submarginal uses of scarce capital. Investment in petroleum exploration and development is indeed expanded to the point where the aftertax rate of return is approximately equal to that which may be obtained on alternative uses of capital. Professor Kahn has summarized the misallocation effect as follows:

> The fact that net returns on investment after taxes in the oil industry may not be unusually high thus constitutes not a defense of the (percentage depletion) allowance but the clearest possible proof of the misallocation it causes.[13]

Oil industry spokesmen have defended their various subsidies with the question: If we receive all the subsidies which our critics allege, why is our rate of return on invested capital not substantially higher than other nonsubsidized industries? The answer to this question is that a subsidy will raise the profit rate at the point in time at which it is conferred. Its effects, however, are eroded away with time as producers react to their more profitable situation by expanding into otherwise submarginal areas. This expansion leads to a decline in the rate of return toward a normal yield and to resources misallocation as well.

The oil-spillage case in the Santa Barbara Channel is directly related to the subsidy system. Leases were purchased and drilling occurred in the California offshore area because such operations were made profitable by the subsidy legislation. Under free market conditions, oil prices would be substantially lower, tax costs substantially higher in the oil industry, and the profit inducement to buy leases in the channel

[13] A. E. Kahn, op. cit., p. 205.

would probably be lacking. To develop oil from such sources is to use up more economic value than is produced. In addition to this probable waste of resources, we have the external cost—aptly called spillover costs even before this oil-spillage case—of environmental pollution.

Data are not available to test the proposition that removal of oil subsidies would remove the economic incentives to buy oil leases in the Santa Barbara Channel. Production records are not yet available on the Federal leases, and may never be. Further, oil companies do not disclose their estimates of probable production, revenue, and costs of exploring for and developing the channel oil resources.

However, we do have 14 years of data for the 1954 and 1955 Federal leases on the Outer Continental Shelf offshore from Louisiana. From the record of oil and gas production on these leases, a projection of future revenue may be made. We know that bonus payments totaling $216 million were paid for these Federal leases. These bonuses in total represent the bidder's best estimates of the discounted present value (in 1954 and 1955) of expected future net income after taxes for these leases. We have precise information on all physical production of oil and gas by years from the leases, annual rental payments, royalty payments, and wellhead value for oil and gas. Reliable estimates may be made for presale exploration cost, well drilling and equipping cost, and operating cost.

Revenue from oil production, actual through 1967 and projected thereafter to the year 2000, may be adjusted downward to the point where the U.S. crude price is equal to the world price on a delivered basis to East Coast ports. A price decline amounting to $1.332 per barrel is assumed.[14] This adjustment would follow from the removal of the existing quotas and tariff, making prorationing unworkable. Further, tax costs may be adjusted upward from the 6 percent average rate actually paid by the 22 largest oil companies, to the 48 percent statutory rate. These adjustments to compensate for the removal of the major subsidies not only eliminate the entire $216 million of discounted present value—the bonus payments—but in addition result in an internal rate of return on the 1954–55 leases amounting to only 4.5 percent after taxes. This assumes zero bonus payment. These findings indicate that if oil companies expect to earn more than 4.5 percent, and they do, after taxes on their oil development investment, they should have regarded the 1954–55 leases in total as having no present value.[15] This evidence lends support to the assertion that oil leasing in the Santa Barbara Channel would not have taken place in the absence of the subsidy system.[16]

Congress is now considering bills to prohibit further drilling and production of oil from the channel area. If the system of subsidies is retained, such legislation may be necessary. However, the root of the problem lies elsewhere and it seems futile to prohibit, in new legislation, what is made very profitable by existing legislation.

[14] See table 1. World prices are assumed to be unaffected by the removal of U.S. subsidies. Further, the increased efficiency in domestic production that would result from removal of MER prorationing in the Louisiana outer Continental Shelf area has not been considered.

[15] Since some tracts were regarded as more promising than others, bids might have been submitted on some of the tracts, even under a no-subsidy system.

[16] We know that some physical conditions in the channel differ substantially from those in the Gulf of Mexico. In the California OCS area, water depths are greater, drilling costs are higher, and production is more hazardous due to the geological structure of the area. On the other hand, the U.S. Department of the Interior study of import quotas estimated that in region V the price decline due to the removal of quotas would be 20 cents per barrel less than for the Gulf of Mexico.

I would recommend that steps be taken to internalize the external costs that society bears in the form of environmental pollution; that is, to make oil companies fully liable for all public and private damage.

I would further recommend that the system of subsidies described here be phased out over a period of about 5 years.

When the important external costs (and benefits) are internalized, and when subsidies are removed, private and social benefits from oil production will more nearly correspond. Only when these two steps are taken will the massive burden of resource misallocation in this industry be removed as a drag on this Nation's strength.

Senator KENNEDY. One of the points that you made in the course of your testimony in referring to Adelman's comments yesterday is the cost of this program, and Adelman put the figure at about $4 billion. I have heard anywhere from $4 to $7 billion annually. What would your estimate be on this?

Dr. MEAD. I would simply say that it is today greater than $4 billion. If someone estimates $7 billion, I have no basis for disagreement. I am sure it is more than $4 billion.

Senator KENNEDY. Now, obviously, one of the purposes of the depletion and other tax advantages that are given to the oil industries is to encourage exploration with the idea, I would think, that the industry would become more competitive within itself.

Dr. MEAD. Right.

Senator KENNEDY. And that, as a result of competition and with the not inconsiderable resources which are available in the United States in terms of oil underground as well as the potential for the development of the oil shale, that we ought to see a reduction in the cost of oil products.

I think the record shows quite clearly that that has not happened, and what we have seen to the contrary is an increase in the price to the consumer. And I am wondering just why you believe that this is the case. As I understand, the cost of crude oil in Europe has declined rather significantly, up to 25 percent in the last 3 years.

Dr. MEAD. But it has not declined in the United States. The cost of crude has gone up here due to the restrictions we have been discussing.

Senator KENNEDY. So, where do you put that burden? I mean, why are we not getting a lowering of cost?

Dr. MEAD. Well, the reason we are not getting a lowering of costs is primarily the import quota has not permitted a decline. It has, in fact, produced an increase in the price of crude in the United States.

Now, I would maintain and I am sure Professor Adelman would agree with me, that if we removed the quota system the price would go down. My estimate is it would go down $1.32 a barrel. If that happens, I would further expect that the price of petroleum products, gasoline, et cetera, would decline. I do believe that the oil industry is sufficiently competitive and efficient so that, if the price of crude declines, these benefits would be passed on to consumers in the form of lower prices. I think the oil industry is sufficiently competitive for that effect to take place.

Senator KENNEDY. Now, what is the role that the prorationing plays? You talked a bit about it during the course of your testimony on the cost to the consumer again.

Dr. MEAD. Well, the role of prorationing is probably twofold. It determines, under what they call the MER prorationing, which wells are allowed to produce and how much.

A great deal of inefficiency is introduced. For example, the most efficient wells, the most productive wells, are the ones where operations are curtailed and in both Louisiana and Texas, the two largest producing States, the present permitted output is less than 50 percent of the maximum efficient rate.

The most efficient wells are curtailed. The least efficient wells, the stripper wells, are allowed to produce without restriction in some States. These are the least efficient wells. These are the ones that should be out of business. So, prorationing introduces a lot of inefficiency.

Second, prorationing restricts output in order to hold the price up.

Senator KENNEDY. Well, I suppose they would say that we have to restrict output so that we are going to be able to conserve our resources in the ground, and how would you respond to that? It is necessary even to keep those inefficient wells moving because——

Dr. MEAD. I would deny that is the case.

Senator KENNEDY. They argue that you have to extract the oil at a certain speed and if you do not you are not going to be able to extract as much. Therefore, considering the national security, we ought to proration to assure that we are able to extract as much mineral as possible.

How would you respond to that?

Dr. MEAD. Well, the first type of prorationing is intended to produce an efficient rate of extraction. I would recommend to you this Lovejoy and Homan book that goes into this in great detail. MER-type prorationing is supposed to produce an efficient rate of extraction. Lovejoy and Homan conclude that it in fact does not, it is so poorly administered.

The second point is I firmly deny that market demand prorationing is intended to produce an efficient rate of extraction, and instead I assert that market-demand prorationing is intended only to raise the price of oil, and I have given reasons for that in my paper.

Right now you know that the price of crude has been raised. There have been only very slight increases in the market-demand prorationing figure. This is the time to raise the market-demand prorationing allowable.

Senator KENNEDY. Article V of the Interstate Oil Compact specifically denies any price fixing intent. It says:

> It is not the purpose of this Compact to authorize the states joining herein to limit the production of oil and gas for the purposes of stabilizing and fixing the price thereof, to create or perpetuate monopoly.

Do you in effect, believe that it does?

Dr. MEAD. Yes, I do. The economic analysis clearly shows that that is the case. If you restrict output, you are going to get a higher price. If that is incorrect, the a couple of hundred years of economics are nullified.

Senator KENNEDY. Well, do you have recommendations of what we might do specifically on that?

Dr. MEAD. I have given two in my paper. One is to phase out the whole system.

Senator KENNEDY. That is over the 5-year period?

Dr. MEAD. Over a 5-year period, yes.

Senator KENNEDY. Now, let me ask, why would it not make some sense to give the full depletion allowance to the smaller companies, along the lines that have been suggested by the Proxmire amendment which provides a scale so that you get a depletion allowance for the small companies that might be willing to take chances on wildcatting? You give them the full depletion allowance and you reduce the depletion allowance as you get into the majors. Does that make any sense, to provide a scale, the idea being to stimulate and assist the smaller operations?

Dr. MEAD. I would personally have great reservations. I do not see why anyone needs a subsidy in that area. I would withdraw it from all. I believe that a small producer can very effectively compete with a large one and does not need a subsidy. I would remove it from all. You run into all of the same resource misallocation problems all over again if you give it simply to the little guy. He can compete all right. He is doing very well.

Senator KENNEDY. Could you talk a little bit about the import licensing program? Who gets the real benefits of these licensing agreements?

Dr. MEAD. That is a very interesting and very complex system. As you know, as soon as we restrict imports, we create a value. It is a value paid for by the consumer in the form of higher prices. That value now amounts to roughly $1.25 per barrel of imported oil.

Now, that $1.25 value is given away. It is given away to those who qualify on the basis of refinery through-put. It is given on the basis of past production records supplemented by new entries. It is a value given away.

About a year ago, Secretary Udall proposed that we have an auction to sell that publicly created value. If you are going to have import quotas, this is a good idea, to recover for the public the value which the public pays. What happened was that proposal was circularized in the industry. The industry reacted violently, as anyone would suspect and forecast that they would, and he withdrew the proposal. So we continue to give away this public value.

Yesterday you recall Professor Adelman suggested that he had some surprise that there was no scandal. What he was getting at is you have created a value here and somebody has to allocate that value. If you allocate the right to import 100,000 barrels a day and provide an import ticket, you are allocating something that is worth $125,000 a day.

Now, this opens an opportunity for all kinds of corruption, and the fact that we have had very little is a great testimony to the honesty of our public officials.

Senator KENNEDY. So, who gets those licenses for the most part? I mean, could you give us sort of an idea? Is it the smaller companies that get it or is it the majors that get it?

Dr. MEAD. Across the board. Small companies, big ones, inland refiners, some that are nowhere near a port and could not possibly import and refine foreign oil.

Senator KENNEDY. What do the inland refiners do?

Dr. MEAD. They by and large trade their licenses to someone who can use them. The proclamation forbids them to sell them but permits trading. So, they trade and in effect receive a market value of $1.25 a barrel for their quota, their ticket.

Senator KENNEDY. So this public value that is artificially created in no way benefits the consumers——

Dr. MEAD. In no way whatsoever.

Senator KENNEDY (continuing.) That you know about.

Dr. MEAD. In no way whatsoever, that I know about.

Senator KENNEDY. So this in addition is another subsidy, is that correct?

Dr. MEAD. That is correct. It goes to the people who happen to receive the tickets.

Senator KENNEDY. In your earlier testimony you indicated that it was these incentives that stimulated the development out at Santa Barbara with the attendant disaster that we experienced there. Could you expand on that a little bit?

Dr. MEAD. Yes. The case that I am making is that drilling offshore Santa Barbara——

Senator KENNEDY. You know, in the initial phases of it we heard the Secretary of the Interior say that the problem out in Santa Barbara was that the Federal officials were not enforcing the regulations. That was his first reaction to it.

Is that the reason that you think Santa Barbara happened?

Dr. MEAD. With the benefit of hindsight, it apparently is true that, if a pipe, protective pipe, had been sunk more than—what is it, 349 feet or something of the sort—had been sunk for a 1,000 feet or so, the blowout would not have occurred and this is a matter of regulations. I am not an expert in that area, so I am merely repeating what I read in the newspaper.

My point is different. My point is that if a free market price of oil prevailed, and if costs were not artificially reduced through taxes, it would not pay an oil company to be out there and they should not be there. The fact that they are out there in that high-cost area is misallocating the Nation's resources. That is my point.

Senator KENNEDY. And, of course, I suppose we have a situation where the amount of production is controlled, as I understand it, by the Interior Department, is it not?

Dr. MEAD. The amount of production is controlled by prorationing throughout the Nation in the prorationing States. Are you speaking specifically——

Senator KENNEDY. I am talking about the offshore. I am sorry. That is Federal land. Excuse me. Out in Santa Barbara it would have been State land.

Dr. MEAD. The case of the spillage is on Federal land. And that production is not subject to prorationing. California is zone 5, and is not subject to prorationing. It is a deficit area. There are no controls on production that I am aware of out there.

Senator KENNEDY. I guess Louisiana offshore is——

Dr. MEAD. Louisiana offshore, even Federal, is subject to Louisiana State prorationing rules. This is a case where the Federal Government accepts the decisions of a State, the State of Louisiana, even though the Federal Government owns the land beyond the 3-mile limit. They have accepted State jurisdiction on prorationing, but there is no prorationing offshore from California.

Senator KENNEDY. As I understand it, the oil import proclamation itself requires the Office of Emergency Planning to determine whether any price rise in oil products is in the interest of national security. Do you see any possible justification for the recent oil and gas price rises in national security terms?

Dr. MEAD. None whatsoever. There is an easy way to stop it and that is for the State of Texas, the State of Louisiana, to raise their market-demand prorationing restriction, eliminate it entirely.

Senator KENNEDY. I suppose if the States are not willing to do that, it is not unreasonable to assume that the Federal Government could go ahead and import more oil.

Dr. MEAD. This is another way to stop it. So, if the Federal Government is really interested in combating inflation, it should remove import quotas.

Another thing the Federal Government can do is to eliminate prorationing from offshore areas, the Texas-Louisiana areas.

Senator KENNEDY. And then they would be able to really——

Dr. MEAD. Then they would be able to produce more efficiently at lower cost, and there would be a lower price of crude.

Senator KENNEDY. And what do you think would be the ramifications in, say, for example, Louisiana? If you had an increase in production do you believe it would have adverse effects on the economy of Louisiana?

Dr. MEAD. In the short run it probably would because it would reduce the price of oil. It would also have shortrun effects, perhaps, in Texas that are adverse because it would reduce the price of oil.

Senator KENNEDY. Well, I suppose that efficient wells in Louisiana might actually benefit from the elimination of prorationing.

Mr. MEAD. Yes. If you want to speak of the efficient producer, the high-quality fields, those fields would probably operate at an advantage without restrictions because present restrictions are forcing them to operate at an inefficient level. In the absence of restrictions they would operate at a point which they would consider most profitable. It is true that price should go down but their costs should go down also, and perhaps more than price.

Senator KENNEDY. At least this is an open question, is it not?

Dr. MEAD. It is an open question, right.

Senator KENNEDY. Let me ask a final question. It was suggested yesterday that the most important questions involved in this field have never really been seriously discussed and studied, and I think Mr. Adelman said yesterday it was because the important and significant material and evidence has never been made available to professionals like yourself who have the understanding and the experience and the knowledge, but are denied access to the kinds of significant information which would be necessary for a serious study of the oil import program and its effects on national security.

Now, as I understand it, President Nixon has directed a major reassessment of the program——

Dr. MEAD. For import quotas.

Senator KENNEDY (continuing). And is now considering a complete review of that program. I would assume that with the access to information that he has in the Interior Department, Commerce Department, the Treasury Department, and the Council of Economic Advisers, that the information would be available to the White House and that it would be possible to make a considered judgment on this oil importation question.

I am wondering how long it would take really. How long do you think it should take to get some kind of a result from this study? I mean, if you had that information available to you, say, with Mr. Adelman and maybe one or two of your friends that you have some confidence in, how long do you think it would take to make recommendations on the oil import program?

Dr. MEAD. Well, if full information were available, such a recommendation could probably be produced in a matter of a couple of months. However, as Professor Adelman pointed out, full information is not available. Just as we concluded a few moments ago that it is an open question of the effect in Louisiana of changing the rules, it is open because we do not know the cost of production by wells. That is private information, not publicly available.

Senator KENNEDY. But if that information were gathered and available, I would think in terms of perhaps 60, 90, or 120 days. Would this seem reasonable?

Dr. MEAD. I should think that would be adequate.

Senator KENNEDY. I think we are talking really about 3 months, perhaps 4, after which we could expect some kind of decision. Because I think everybody who has been interested in this question and problem realizes that this has been studied to death, though perhaps not with all the facts and figures that one might like.

Just as a final question, realizing that this program costs about $4 billion a year, and it could go as high as $7 billion this program, I am reminded by counsel here, has just had its 10th anniversary a day or so ago. It has been in effect for 10 years. My mathematics would indicate that this program has cost anywhere between $40 and $50 billion to the consuming public of this country. I am just wondering whether you would agree with that?

Mr. MEAD. Yes; in part. What counsel has reminded you of is that import quotas went into effect 10 years ago, but depletion allowance is now 43 years old, and prorationing was instituted in the midthirties. So, actually, the cost would even be greater than you estimated.

Senator KENNEDY. Do you have any ball-park figures on those?

Dr. MEAD. No; I do not. I am sorry. They could be worked up but I do not have them at the moment. They are astounding.

Senator KENNEDY. In terms of hundreds of billions of dollars?

Dr. MEAD. Perhaps.

Senator KENNEDY. Professor, I want to—Senator Fong?

Senator FONG. Mr. Mead, it seems that the market-demand prorationing is actually the real joker in this whole situation, is it not?

Dr. MEAD. It is part of it. It is reinforced by imports quotas?

Senator FONG. Yes. Now, if you did not have the market-demand prorationing, you probably would have reduced prices.

Dr. MEAD. Yes; especially if you got rid of import quotas.

Senator FONG. Now, even with import quotas, your marketing-demand prorationing is one which is looked at every month, is that correct?

Dr. MEAD. That is correct.

Senator FONG. So that, if the price should go down, then immediately they stop you from pumping.

Dr. MEAD. They slow it down; yes.

Senator FONG. They slow it down. So if that was eliminated it would help materially, even if you had import quota restrictions?

Dr. MEAD. It would, indeed.

Senator FONG. And even if you had maximum efficiency prorationing.

Dr. MEAD. It would, indeed.

Senator FONG. Now, would you go as far as to say that we should not have any maximum efficient rate of production?

Dr. MEAD. No, sir. No. We need some kind of MER-type prorationing. The reason is, given a pool of oil that is owned by several producers, one will compete with another to get that stuff out of the ground as quickly as possible, and too quickly for maximum efficient production. So, some kind of unitization or MER prorationing is needed. There is no question about that in my mind. It is this added market-demand prorationing that is the difficult point.

Senator FONG. What do you say to market-demand prorationing? Do you think there should be some form of that?

Dr. MEAD. I think it is totally inexcusable in an economy that believes itself to be a free enterprise economy. This is a monopolistic practice and should not be tolerated, in my opinion.

Senator FONG. You feel that that should be entirely eliminated.

Dr. MEAD. I do, indeed.

Senator FONG. Now, as far as import quotas, do you think that there should be an import quota?

Dr. MEAD. If I had my "druthers," I would phase import quotas out over a period of time, and I have suggested 5 years. I would be happy to have it phased out in 10 years. I see no need in the long run for import quotas. The only justification ever made for them, apart from the obvious one, that it raises prices, the only justification ever made publicly is the national defense justification.

Senator FONG. That was the thrust of the—that was the rationale of these import quotas.

Dr. MEAD. That is correct.

Senator FONG. When it was finally adopted.

Now, what do you say as to how our national security would be endangered or not endangered by the elimination of the import quotas?

Dr. MEAD. With the elimination of import quotas, imports would go up. How much they would increase I do not know. But they would increase substantially. This would make us in peacetime at least more dependent on foreign oil than we are now.

It is not true, however, that domestic reserves would decline to zero. Right now domestic reserves are about 11 times current production and use. I should imagine that those reserves would decline and perhaps to 5 or 6 or 7 years, and that is quite a reserve. But my real point is in another area, and that is to say that this whole rationalization of national defense came before the development and knowledge about our oil shale reserves.

You see, we know a great deal now about these reserves. We know something about the cost of producing oil from shale. A study recently completed by the Department of the Interior showed that you can recover those reserves even from a relatively inefficient first-stage plant and get a rate of return of about 13 percent on the investment of about $150 million.

Now, that is reasonably attractive. And it provides us with a relatively low-cost means of taking care of our national security needs. The present way we are taking care of our national security needs is extremely expensive, something in excess of $4 billion a year. We can proceed with development of oil shale reserves and make them available in case of national defense needs. They are far better than, say, offshore oil which is vulnerable to attack. And the oil shale reserves are so vast, utterly vast.

Senator FONG. Over a trillion barrels?

Dr. MEAD. Well, you can go to 2 trillion. Estimates run that high. But one way of expressing it is this way. If you take the reserves that have more than 10 gallons per ton in them, we have more oil in shale, in fact, three times as much as the known crude petroleum reserves in the entire world, including the Middle East. Now, that tells us that there is no problem of availability of oil. It is nothing but making the facilities available to produce it. And that can be done relatively cheaply.

Senator FONG. And the discovery of the Alaskan oil fields also adds to the national——

Dr. MEAD. That adds to it further.

Senator FONG. So, you would propose instead of subsidizing the industry to the tune of $4 billion per year—is that it?

Dr. MEAD. Yes, that is about right.

Senator FONG. That part of that be used for the exploration and development of the oil shales, the marginal fields, to bring them up so, in case of an emergency, we will have that supply.

Dr. MEAD. Correct. I think the national defense argument has lost much of its punch.

Senator FONG. And the implementation of the import quotas was due primarily to the fact that national security demanded it.

Dr. MEAD. That has been the rationalization.

Senator FONG. So from that standpoint you feel within 5 or 10 years we could eliminate the import quota.

Dr. MEAD. Yes, sir.

Senator FONG. Now, specifically talking about the import quota, as you know, the import quota divides the country into five districts.

Dr. MEAD. Yes.

Senator FONG. Do you feel that there should be such a division, even though we may have an import quota?

Dr. MEAD. Well, yes——

Senator FONG. Is it not discriminatory that certain districts—that we do have these district zones?

Dr. MEAD. Yes, it is. However, there are real differences. The west coast is, in fact, a deficit area and the area east of the Rockies is, in fact, a surplus area. So, I think there is some justification for treating those two regions differently. However, if you get rid of import quotas then, of course, there is no need——

Senator FONG. You refer to tickets being worth from 95 cents to $1.25 per barrel.

Dr. MEAD. Correct.

Senator FONG. You come from California.

Dr. MEAD. Yes.

Senator FONG. And I think probably you may have had some notice that there is quite a stir in the State of Hawaii relative to the cost of oil.

Dr. MEAD. Yes. I read a bit about it.

Senator FONG. And the people of Hawaii feel that they are paying $14 to $15 million a year more than they should be paying. And they cannot see Standard Oil importing oil from Indonesia and South America and bringing the oil to Hawaii and then refining it and then charging the people of Hawaii the cost of oil, which is at the price prevalent on the West Coast plus 60 cents per barrel to bring it from the West Cosat to Hawaii, on the theory that they have bought tickets from other refineries so that they have to make up for that purchase.

Dr. MEAD. Yes.

Senator FONG. You agree with me that this is quite absurd, is it not?

Dr. MEAD. Senator, I think there is a full explanation available for that in textbooks on monopoly. This is monopoly behavior. And it ought to be looked into. I do not think it would prevail if competition prevailed.

Senator FONG. Pursuing that policy, as an outcome of that policy, the Honolulu Gas Co. in Hawaii has started a move to have a refining zone, a foreign trade refinery, having a certain section of the islands declared as a foreign zone, and in that foreign zone they intend to build a refinery, and all of the refined products are not to come into domestic use but for sale outside of the State of Hawaii and to the military which now is permitted to buy these bonded things which are not refined in the United States.

We have been trying to get a license. The Interior Department has had regulations so that we could proceed under the importation of oil. But we have not yet received a license from the Commerce Department, which handles the import zones.

Now, as an economist you would agree that a license should be granted under those circumstances, would you not?

Dr. MEAD. I should think you would be far better off with the kind of free trade zone that you are describing. I would suggest in addition you would benefit from having some other companies in there to compete with Standard Oil of California.

Senator FONG. I was coming to that. I asked Mr. Gary of the Honolulu Gas Co. as to why we did not go for a free—for an elimination of the quota.

Dr. MEAD. There you would be better off.

Senator FONG. And he said not yet. Let us establish a few more refineries so we have competition, and he says, even if you had a zone and you did not have competition, you will still be up against high prices.

Could you talk to that point?

Dr. MEAD. It is hard to speculate on what would happen. I certainly agree that if you have two or three additional competitors there, and if you have an elimination of import quotas, you would be far better off than you are now, and I suspect that the price you are paying for your crude would be approximately cut in half. I have not studied it carefully but it would be something like that.

Senator FONG. Mr. Mead, I have read your statement, I think three-

discussion of the problem. I think your statement has been very, very helpful to me in the understanding of this problem. I want to thank you.

Dr. MEAD. Thank you very much.

Senator FONG. Dr. Blair?

Dr. BLAIR. Professor Mead, the uniquely valuable part of your statement is the way in which you show how one form of governmental intervention into the market mechanism breeds another. Each one engenders a successive form of restraint. Your depiction of the process by which this has taken place in the oil industry is most illuminating, starting with percentage depletion which re[illegible]ults in excessive production which then must be limited by mark[illegible]nd proration, the Interstate Oil Compact Commission, and so [illegible] Then because there is a limitation on domestic production but none [illegible] foreign supplies, import quotas must be established. Hence, we find ourselves as a result of this process shackled with a whole variety of contr[illegible], each one of which is more or less the inevitable and expected product of what has gone before.

Is that more or less the substance of your presentation?

Dr. MEAD. That is a fair statement of my position; yes.

Dr. BLAIR. It is a remarkably penetrating analysis.

Dr. MEAD. Thank you very much.

Dr. BLAIR. In your discussion of the immediate impact of a subsidy you state:

> Its effects, however, are eroded away with time as producers react to their more profitable situation by expanding into otherwise submarginal areas.

After they make that expansion, then apparently [illegible] need for some control on the produ[illegible]sion. Would you say that the process [illegible]?

Dr. MEAD. In a sense, yes. It is ad[illegible]ve in the sense that, every time one of these new subsidies is added, it will create an immediate windfall profit for all the firms that can benefit by it. That immediate windfall profit can, as you say, be addictive in that you will need another windfall profit a few years later to maintain your past growth rate in, say, profit rate per share.

Dr. BLAIR. With respect to your comment on Professor Adelman's suggestion yesterday that there was need to secure more data before any meaningful conclusion could be drawn as to policy decisions, I presume what he was referring to primarily was cost data.

Dr. MEAD. I think so.

Dr. BLAIR. As veterans of this subcommittee will recall, we have spent about 10 years off and on trying to obtain cost data, usually with remarkably little success. The reason for failure is understandable. Producers regard cost data as trade secrets—as a type of information which if divulged or disclosed would be of benefit to their competitors.

It would be nice to have a group of economists before whom the cost data could be spread and whose deliberations, based thereon, could provide the basis for public policy. But would you not agree, based on past experience, that the likelihood of any governmental body actually securing this data is rather remote?

Dr. MEAD. I agree.

Dr. BLAIR. Even from a substantive point of view, if cost data were obtained, they would reflect costs prevailing under existing levels of be if production restraints were eliminated? If wells in low-cost areas were permitted to maximize their production within some form of unitized field limitation, to what extent would their existing costs fall? An answer to this question is not to be obtained by surveys of existing costs.

Dr. MEAD. That is correct.

Dr. BLAIR. Do you agree?

Dr. MEAD. That is right.

Dr. BLAIR. If a policy decision must wait until we have all the data which ideally we should have, we may be waiting far longer than even your 10-year phaseout period.

Dr. MEAD. I agree.

Dr. BLAIR. The decision to put the quota into effect was taken without the existence of cost data, adequate or otherwise.

Dr. MEAD. But if you take any existing well and if you have cost data on that well, variable costs, you know its output. There are occasions where that output is vastly increased as in the two Suez crises. There was an increase in production per well permitted. So that from that record it is possible to get some idea of how much you can increase output under free conditions and what happens to cost. So, if we had that kind of information, it would be possible to make a better estimate about what would happen under the absence of all of these—these massive restrictions.

Dr. BLAIR. Senator Fong may be interested to know that the subcommittee has been doing its best to obtain exactly that kind of data for the most recent Suez crisis. We have encountered some difficulty with the Department of the Interior. We hope that those difficulties will be eliminated.

Dr. MEAD. There is another reason why you need cost information that has not been brought out here. The Government is also a seller of oil resources, and as a seller of resources it has normally a minimum price below which it will not accept bids. It is not in a very good position to estimate what that minimum price is in the absence of more cost information. If it is to intelligently sell its resources, it needs more cost information than it now has.

Dr. BLAIR. In order to clarify the record concerning the delivered price to the eastern seaboard of domestic crude, I would like to go through the arithmetic very briefly.

Your delivered price is about $3.42. Yesterday I presented an estimate of around $3.75. One difference was that, in order to make comparisons with Middle East crude, we were using a gravity of 34 and you are using a somewhat heavier crude of 31 to 31.9. Apparently the difference is about 10 cents.

Dr. MEAD. Yes.

Dr. BLAIR. Then, we added to the price at the wellhead the gathering and pipeline and terminal charges which were in the vicinity of around 20 cents. Then, we used a tanker rate of 50 cents which, according to our understanding, is the current rate applicable for shipment from the Gulf of Mexico to the U.S. East Coast for a 30,000-ton tanker for a 1- or 2-year charter.

Thus the use of a tanker rate which is 30 cents higher than what you have used, plus 10 cents for the gravity differential, would bring us, starting from your base, to about a $3.80 level.

Dr. MEAD. Yes.

Dr. BLAIR. Consequently, I do not think there is any substantial difference between us.

Dr. MEAD. No. And as I tried to point out, this business of pricing, obtaining price information and cost information, on oil is extremely difficult. Different researchers will obtain different figures. My $3.12 figure is a cost at a port, hence it does not have any gathering figure added. It is in Refugio, Tex., which is a port city.

Dr. BLAIR. Would it still have the terminal charges?

Dr. MEAD. I have tried to include those in my transportation costs. However, they are substantially less than yours and I have no reason for saying my figures are any better than yours. My interest here, at any rate, is the difference between the foreign and the domestic, and I estimate $1.32 difference. Your estimate is a little bit higher. Either one is adequate to make the point that I am concerned with. Your estimate makes it even more dramatically than mine does.

Dr. BLAIR. Thank you, Professor.

Senator FONG. Mr. Coulter?

Mr. COULTER. Dr. Mead, one problem is that, if the only way to get foreign oil is to make us dependent on certain foreign nations, I think there is some hesitancy about putting this Nation in that position. Two years ago the Arab countries attempted to use an embargo on their oil as a political weapon.

You mentioned that if the import quotas were abolished there would be an increase in importation of oil.

Can you give us an idea as to where that additional oil would come from? I should say, making the question more precise, what proportion would come from the Arab nations?

Dr. MEAD. I should think that most of it would come from the Arab nations, but I cannot, without looking at it, estimate exactly what it would be. I should think since most of the idle capacity is in the Middle East rather than, say, in Venezuela, that it would come from that area. But you have used the term "dependent." I would want to point out that, while we become more dependent upon them, they also become more dependent upon us.

As was pointed out yesterday, selling oil to this country is at least as important to the Arab countries as it would be to us.

Mr. COULTER. Yes. I am an economist like you are and I tend to look at the economic or financial side of things and I think I should not really be discussing foreign policy matters. However, it appears to me that some of those nations, when they have to choose between the political objective and the financial objective, they always choose the political objective.

Dr. MEAD. Yes. We should ask at what price do we want to avoid this kind of additional dependence. There is a price at which it is too expensive. I think that price is now too high. I believe that we have lower-cost ways of taking care of our national defense needs than the method now being used.

Mr. COULTER. One other question I have. You probably recall, as I do, a couple of years ago, I think, a large tanker went on the rocks in the English Channel——

Dr. MEAD. I recall.

Mr. COULTER (continuing). Presumably loaded with cheap imported oil, and that oil spoiled some very attractive beaches on the English coast.

Is there any difference between the kind of a mess that cheap foreign oil makes on beaches as compared with the kind of mess that the expensive Santa Barbara oil makes on beaches?

Dr. MEAD. In either case it is thick and black and gooey and it makes a big mess.

In my first recommendation I have proposed that the costs of water pollution which society has to bear be internalized. I think I would apply the same point to shipping of oil. Society does run a big risk as tankers may go aground and the oil spread around. I believe that it would be very helpful to levy some kind of a fee on tank transportation of oil such that a reserve is created to compensate society for those costs. That is, to internalize them. So, I apply the point not just to offshore drilling. I would also apply it to transportation of oil.

Mr. COULTER. From the standpoint of keeping the beaches pretty and avoiding that damage, there is really no difference.

Dr. MEAD. That is correct.

Dr. BLAIR. Mr. Chairman, in that connection, may I make a personal observation? As a young boy I happened to be, with my father and mother, in Santa Barbara at the time of the great earthquake of the mid-twenties. I can still remember the experience of the hotel rocking violently and I can still remember that as we ran out in the street large cracks and crevices appeared in the street. Water from broken fireplugs was streaming into the street. Now, if at that time offshore oil wells had been in operation in the Santa Barbara Channel, they probably would have been simply sheared off by the force of the quake. Since they would have been well underneath the surface, it would have been difficult, if not impossible, to plug up these sheared-off pipes as has been done in the recent disaster.

Dr. MEAD. Has not quite been done.

Dr. BLAIR. Not quite been done?

Dr. MEAD. As I flew over that area on Monday, I saw the platform of Union Oil Co. and the oil slick is now only about one or two blocks wide and is only about 40 miles long at the moment. So, this is very modest compared to what it was 3 weeks ago. But it is not quite plugged.

Dr. BLAIR. Is there a feeling among geologists that the area is now fairly safe from a recurrence of an earthquake of the type that occurred some 40 years ago?

Dr. MEAD. Not at all. The geologists are scared stiff. If you get 60 or so wells from a platform out there in that earthquake-prone area they can be sheared off. You can also get submarine landslides that will shear off the pipes at a higher level.

That is an area that moved, I believe, 60 times last year in earthquakes. But this is another matter, of course.

Senator FONG. Professor Mead, the committee wants to thank you for appearing before it. Thank you for a very, very excellent presentation.

Dr. MEAD. It is a pleasure to be here.

Senator FONG. It will help us materially in the discussion.

Thank you very much.

The committee stands adjourned until Monday, March 24.

(Whereupon, at 12 noon, the hearing was recessed, to reconvene on Monday, March 24, 1969.)

GOVERNMENTAL INTERVENTION IN THE MARKET MECHANISM: THE PETROLEUM INDUSTRY

MONDAY, MARCH 24, 1969

U.S. SENATE,
SUBCOMMITTEE ON ANTITRUST AND MONOPOLY
OF THE COMMITTEE ON THE JUDICIARY,
Washington, D.C.

The subcommittee met, pursuant to recess, at 10:08 a.m., in room 1318, New Senate Office Building, Senator Philip A. Hart (chairman) presiding.

President: Senators Hart (presiding) and Fong.

Also present: S. Jerry Cohen, staff director and chief counsel; Dr. John M. Blair, chief economist; Peter N. Chumbris, chief counsel for the minority; Kirkley Coulter, economist for the minority; Gladys E. Montier, clerk; and Jo Anne Lang, stenographer.

Senator HART. The committee will be in order.

The committee had announced that today we would hear, among others, Professor Engler of Sarah Lawrence. We have been advised that Professor Engler will not be able to be with us today. I would hope that we might have his comment and testimony later in the hearings.

We open with Dr. Paul T. Homan, a most respected member of the economic profession.

For many years Dr. Homan was editor of the American Economic Review, the official publication of the American Economic Association. He has been professor of economics at Cornell, the University of California at Los Angeles, and Southern Methodist. He has also been a senior staff economist with the War Production Board, the Council of Economic Advisers, and other Government agencies.

One of his fields of specialization has been the petroleum industry. Among his more important publications in this field are the Economic Aspects of Oil Conservation Regulation and Cost Analysis in the Petroleum Industry. Each of these books was written in conjunction with Professor Wallace Lovejoy, whom we had invited to testify but who, unfortunately is unable to appear.

Today we have asked Dr. Homan to describe the evolution and the history of the oil import program.

Doctor, we welcome you.

STATEMENT OF DR. PAUL T. HOMAN, FORMER EDITOR, AMERICAN ECONOMIC REVIEW

Dr. HOMAN. Senator Hart and members of the subcommittee, I am very happy to appear before your subcommittee to present some of

PROGRESS REPORT

"Microwave Radiometric Measurements of Oil Slicks and Sea Temperature"

Norman K. Sanders, Assistant Professor of Geography

see next page

013

DETECTION OF OIL SLICK POLLUTION ON WATER SURFACES WITH MICROWAVE RADIOMETER SYSTEMS

J. C. Aukland - W. H. Conway

Microwave Sensor Systems, Inc.
Downey, California

Dr. N. K. Sanders

University of California at Santa Barbara
Santa Barbara, California

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notes: @ IN CUIMR-Q-70-001
@ used as the project progress report with second title

Presented at:

Sixth Symposium
on
Remote Sensing
of
Environment

October 13, 14, 15, 16, 1969

University of Michigan
Ann Arbor, Michigan

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Examination of the theoretical and experimental body of information that is presently available leads to the conclusion that there are two mechanisms by which the presence of oil on a water surface may be detected. Both of these mechanisms create an apparent temperature anomaly when oil is present. It is the presence of this local anomaly in the relatively uniform background of the sea surface that will signify the detection of oil pollution. This paper develops an analytical basis for the mechanisms and presents the results of the experimental verification.

The first phenomena to be considered is measuring the local change in sea state due to the presence of the oil pollution. This phenomena presents very strong signals to microwave radiometers when winds of 6 knots or more are blowing. It is felt that this will be the primary detection mechanism for thin oil films. The second mechanism to be considered is the direct change in the emissivity of the water surface due to the presence of oil. This phenomena is slightly the weaker of the two, but offers the promise of measuring oil thickness. Because of the independence of these two potential detection mechanisms they are described separately in the following paragraphs:

THE CASE OF VARIATIONS IN SEA STATE PRODUCING CHANGES OF RADIOMETRIC TEMPERATURE

The ability of oil to "calm the water" has been known to sea-going men for centuries; however, the ability to quantify this phenomena has not been available until very recently. This is due to the fact that exact measurement of the sea state has not been possible. Determination of the sea state has been a subjective estimation of the value, using arbitrary reference points.

In early 1968 the results of an in-house study at Microwave Sensor Systems led to a program to examine the use of microwave radiometers to measure sea state. The results expected from this on-going sea state measurement program will satisfy the requirement of demonstrating a practical method of measuring sea state. The oil slick pollution measurements have been included, during the summer of 1969, to obtain this portion of the data.* The sea state information was presented in a companion paper[1] at this symposium, with the oil slick effects presented in this paper.

The effects of oil slicks upon sea state were difficult to determine in measurements from pier installations, as the oil was often accompanied with detergent foam and debris. The presence of foam caused an increase in radiometric temperature instead of the decrease expected from oil alone calming the water. However, several measurements were made where oil was present without foam. These measurements show that for relatively calm seas with wind ripple, the radiometric temperature decreased by approximately 4^{o} whenever the oil suppressed the ripples. For sea states of 1 or 2, thin films of oil had similar effects provided wind ripple was present. In higher sea state, the temperature decrease will be even more pronounced. Figure 1 shows Stogryn's[2] predicted value of surface temperature as a function of wind speed. From this curve it is apparent that a decrease in sea state may produce a signature of up to 10^{o}.

*These measurements were made possible by a National Science Foundation Grant.

Larger quantities of oil which suppress the sea state may have different effects. Decreasing sea state will result in colder radiometric readings, but the increased absorption from interference effects for thicker oil films may mask the decrease in sea state effect with a resultant increase in radiometric temperature.

THE CASE OF OIL OVER WATER SURFACE PROVIDING CHANGE IN EMISSIVITY

Following the method that Stratton[3] suggests to determine the interference effects exhibited by a thin dielectric sheet (oil) separating two semi-infinite dielectric media (air and water), it is apparent that the reflection coefficient becomes a minimum when the thickness of the oil film is $\lambda/4$ at the wavelength being observed. This minimum value becomes 0 for the special case when the dielectric constant of the oil is such that

$$\epsilon_{oil} = \sqrt{\epsilon_1 \epsilon_3}$$

or when its dielectric constant is the geometric mean of water and air. Since the emission and reflection coefficients are related by $\epsilon + \rho = 1$, it also follows that the emissivity will therefore become a maximum at this point.

In the general case the apparent temperature of the water surface is given by:

$$T_w = T_{amb} (1-R) + R\, T_{sky}$$

where T_{amb} = Ambient temperature of water

R = Reflection coefficient of water with oil

$$\text{where } R = \frac{(r_{12} + r_{23})^2 - 4r_{12}\, r_{23} \sin^2 a_2 d}{(1 + r_{12}\, r_{23})^2 - 4r_{12}\, r_{23} \sin^2 a_2 d}$$

r_{12} = Reflection Coefficient of the air-oil interface

r_{23} = Reflection Coefficient of the oil-water interface

$a_2 d$ = Path length in oil layer

Both r_{12} and r_{23} vary with the viewing incidence angle and with the relative dielectric constants involved, and are different for each polarization. These coefficients are also calculated from expressions given by Stratton:

$$\rho_H = \frac{(\epsilon_1 - \epsilon_2 \sin\theta_o)^{\frac{1}{2}} - \sqrt{\epsilon_2} \cos\theta_o}{(\epsilon_1 - \epsilon_2 \sin\theta_o)^{\frac{1}{2}} + \sqrt{\epsilon_2} \cos\theta_o}$$

$$\rho_V = \frac{\epsilon_1 \cos\theta_o - \sqrt{\epsilon_2}\,(\epsilon_1 - \epsilon_2 \sin^2\theta_o)^{\frac{1}{2}}}{\epsilon_1 \cos\theta_o + \sqrt{\epsilon_2}\,(\epsilon_1 - \epsilon_2 \sin^2\theta_o)^{\frac{1}{2}}}$$

The angles used here are the sensor viewing incidence angle for the reflection at the air-oil interface, but this angle must be modified by the refraction effects (Snells' law) for the oil-water interface. The path length in the oil film must also be calculated using the refracted angle.

The values of dielectric constants of oil and petroleum products given by von Hippel[4] are closely grouped between 1.9 and 2.16; therefore, it appears that a value of 2.0 is a good average for the general analysis. The value of dielectric constant for water is given to be 49 at 15° C and increases slightly with temperature. Since most of the measurements of interest would involve water between 15° C and 20° C, the value of 49 was chosen as an average. The values of this reflection coefficient have therefore been calculated using values of $\epsilon_1 = 1$ (air); $\epsilon_2 = 2$ (oil), and $\epsilon_3 = 49$ (water).

Calculations for both polarizations have been carried out for nadir angles ranging from 0° (normal incidence) to 75° (15° grazing). These interface reflections have then been combined to form the total reflection term, and the apparent temperature of the water surface calculated using sky temperature variations obtained from Hercules and Brown[5].

The most interesting effects notable from these calculations are contributed by the Brewster angle for oil (occurring at 55° nadir). At this angle change of apparent temperature caused by oil on the water does not appear in the vertical polarization, while it is very prominent in the horizontal polarization. This angle becomes even more interesting considering the fact that it is also near the "invarient" apparent temperature incidence angle for sea state measurements.

EXPERIMENTAL PROGRAM

During the Summer of 1969 a series of measurements were conducted to verify the theoretical approach and the calculations. These measurements were conducted in a small tank (approximately 6 ft. in diameter) containing water, into which the oil film was introduced in the desired manner. The radiometers were positioned over this tank on an adjustable framework to obtain the desired incidence angles. Two radiometric instruments were utilized to obtain measurements at both 10.2 GHz and 38 GHz. The oil used was a mixture of Diesel fuel and motor oil to achieve a combination of low viscosity and coloration for visibility.

Figure No. 2 shows the results of these measurements for the 38 GHz radiometer at 45° nadir angle and horizontal polarization. The data points are shown, with the line representing a "best estimate" average of the measurements. The curve of calculated values of brightness temperature is shown in the figure for comparison purposes. Differences in the absolute values encountered are the result of the data being presented as raw antenna temperature, rather than a brightness temperature as calculated.

A significant dispersion of the data points was encountered near the $\lambda/4$ thickness point as a result of variations in oil film thickness over the surface of the tank. As the thicker portion of the oil passed through the sensor beam the apparent temperature varied markedly. Visual inspection of this "uneven" surface condition was used to verify this phenomena. The measured values never exceed the values indicated by the dashed lines. These then represent boundary values for the apparent temperature, and define maximum and minimum points on the curve.

Figure No. 3 is a plot of the vertical polarization data at the same nadir angle. From the relatively small dispersion of data points, and the lack of variations encountered in the measurements near the $\lambda/4$ point, it is apparent that the Brewster angle is near, and the antenna temperature is relatively insensitive to film thickness.

Figure 4 shows the calculated and measured value of temperature at 55° nadir angle for the 38 GHz radiometer with vertical polarization. Here the uniform calculated temperature with thickness variations indicates the presence of the Brewster angle. The increasing value of measured points indicates that the oil used for this measured was not "lossless".

Figure 5 is a sample of similar data taken at 10 GHz showing the horizontal polarization component. Here the slope of the curve is following the calculated value, but the magnitude has not yet reached a peak. This is most likely a result of the dielectric constant of this particular sample of oil being different from the 2.0 value assumed for the calculations. Unfortunately, the experiment had to be concluded at the 5 mm thickness point because no more oil was available at the measurement site.

Summary

Examination of the data obtained during this program reveals that oil on a water surface behaves in a manner that causes two separate and distinct effects. Thin layers of oil produce a lower radiometric temperature than the surrounding sea by reducing the number and size of small capillary waves produced by the wind. This effect can produce a signature of up to 10 degrees.

When the oil film becomes thicker, it causes the apparent temperature to increase due to the effects of a dielectric layer on the water surface. For an operating frequency of 38 GHz, the crossover point for these two phenomena occurs in the range of 0.1 to 0.3 mm, depending on the wind speed. Thicker oil concentrations caused very hot signature, up to 100° at 1.0 mm thickness, to be generated.

CONCLUSIONS

Microwave radiometers offer a means of detecting and tracking oil spills in the open ocean, on an all weather, day and night basis. Care must be taken in applying these techniques, since it is possible to obtain combinations of oil thickness incidence angle, and wind speeds that could render spills invisible.

Fortunately when oil of this thickness range exists, it is also possible to obtain a measurement of its thickness. It is felt that these techniques can offer a significant capability that is not presently available.

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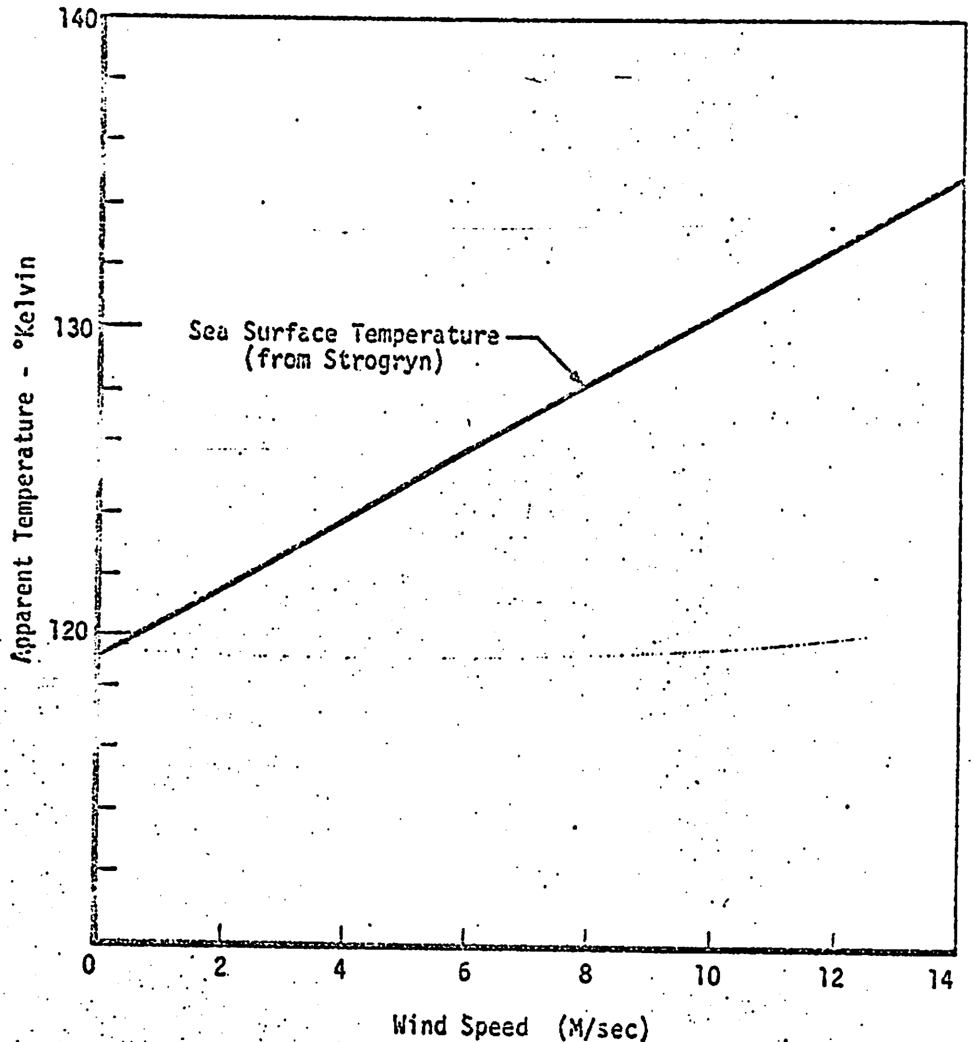

Fig. 1 - Predicted Sea Surface Temperature

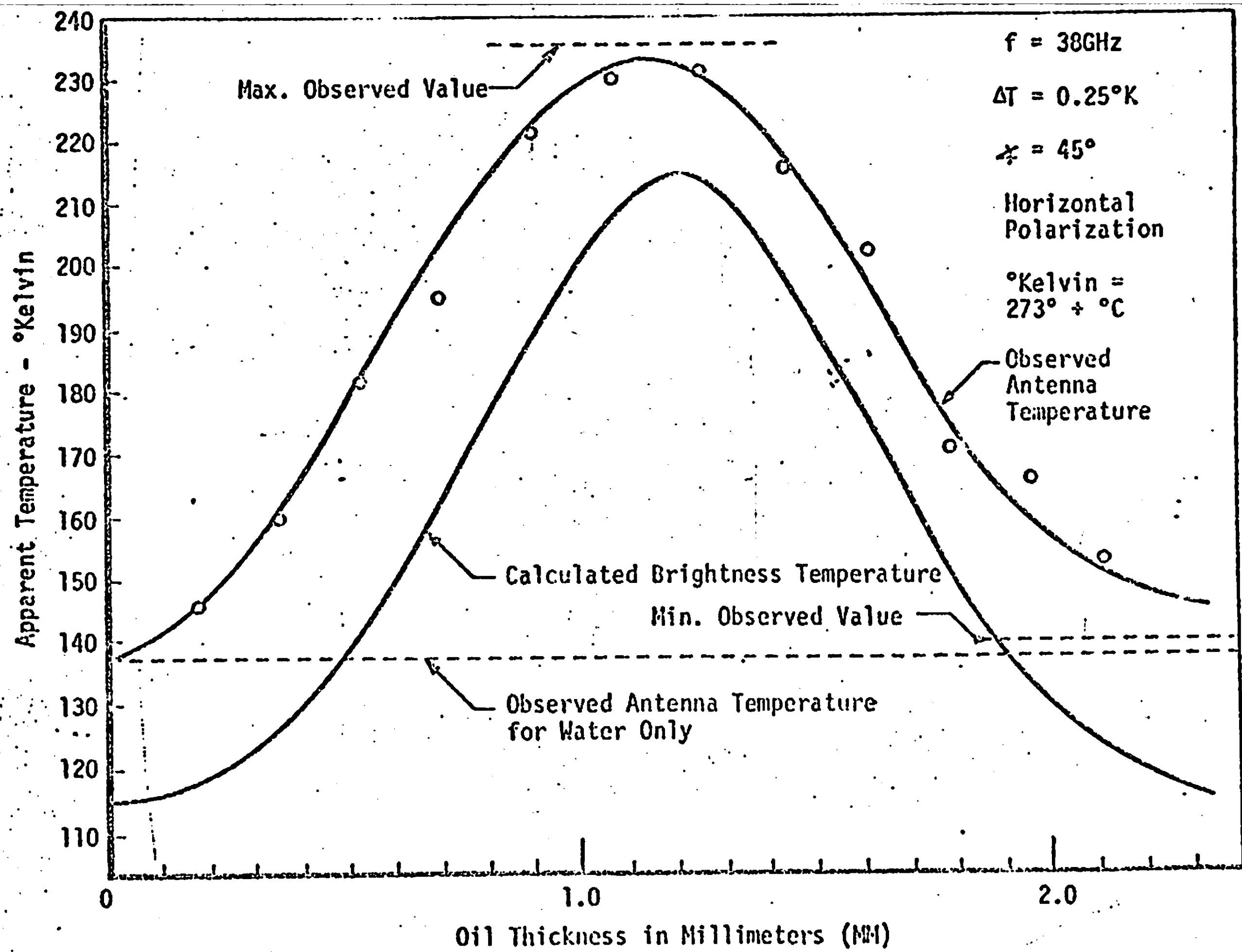

Fig. 2 - 38 GHz Measurements - Horizontal Polarization

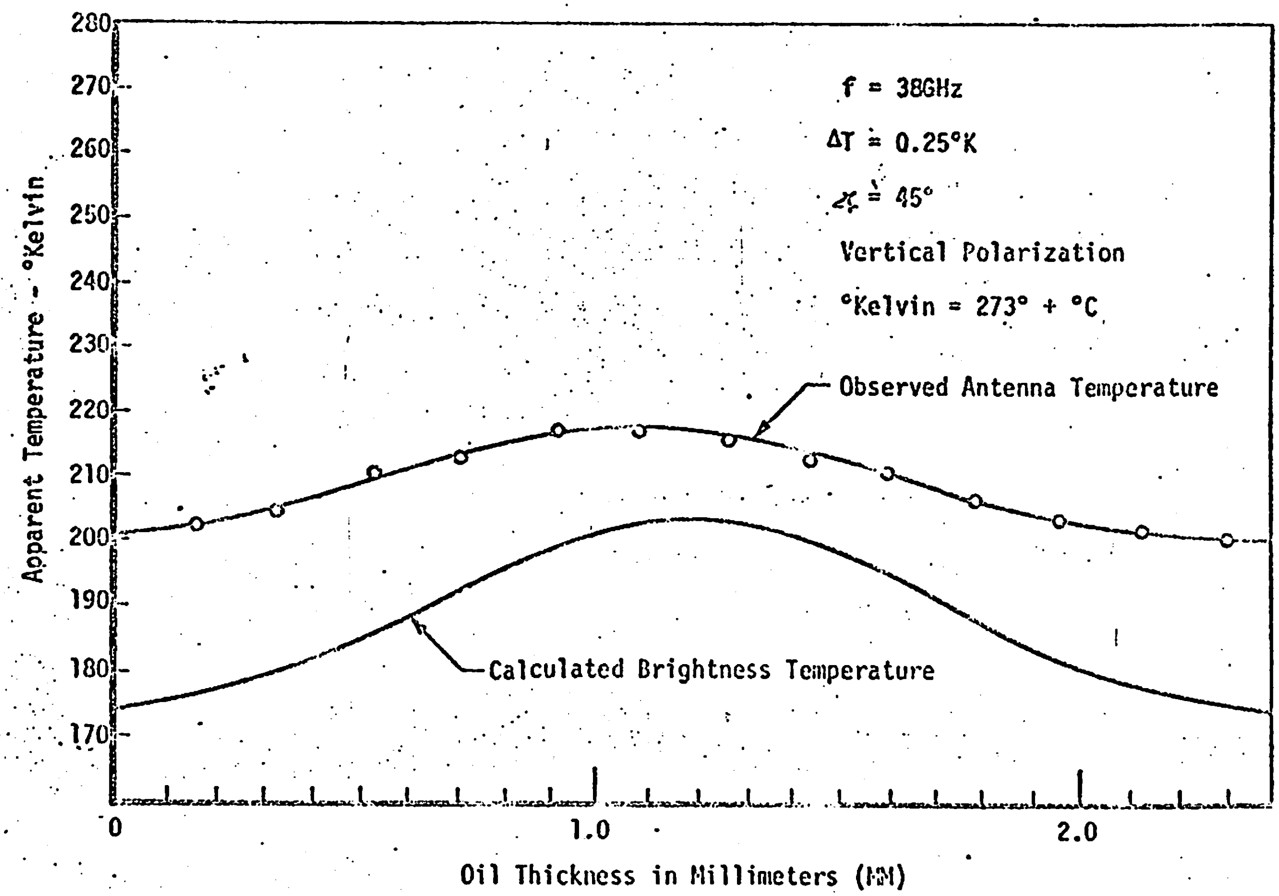

Fig. 3 - 38 GHz Vertical Polarization

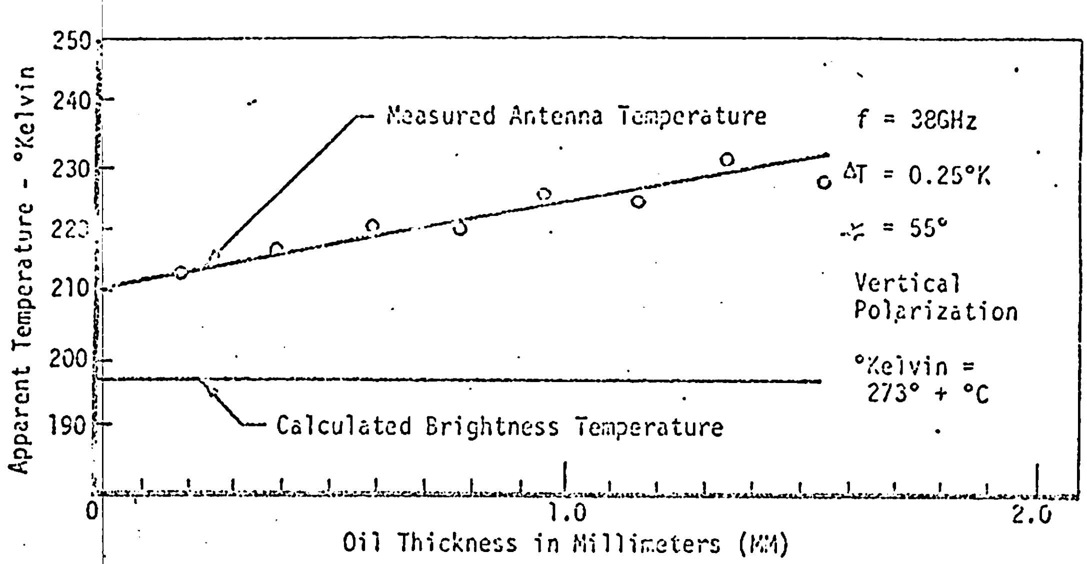

Fig. 4 - 38 GHz Brewster Angle Measurement

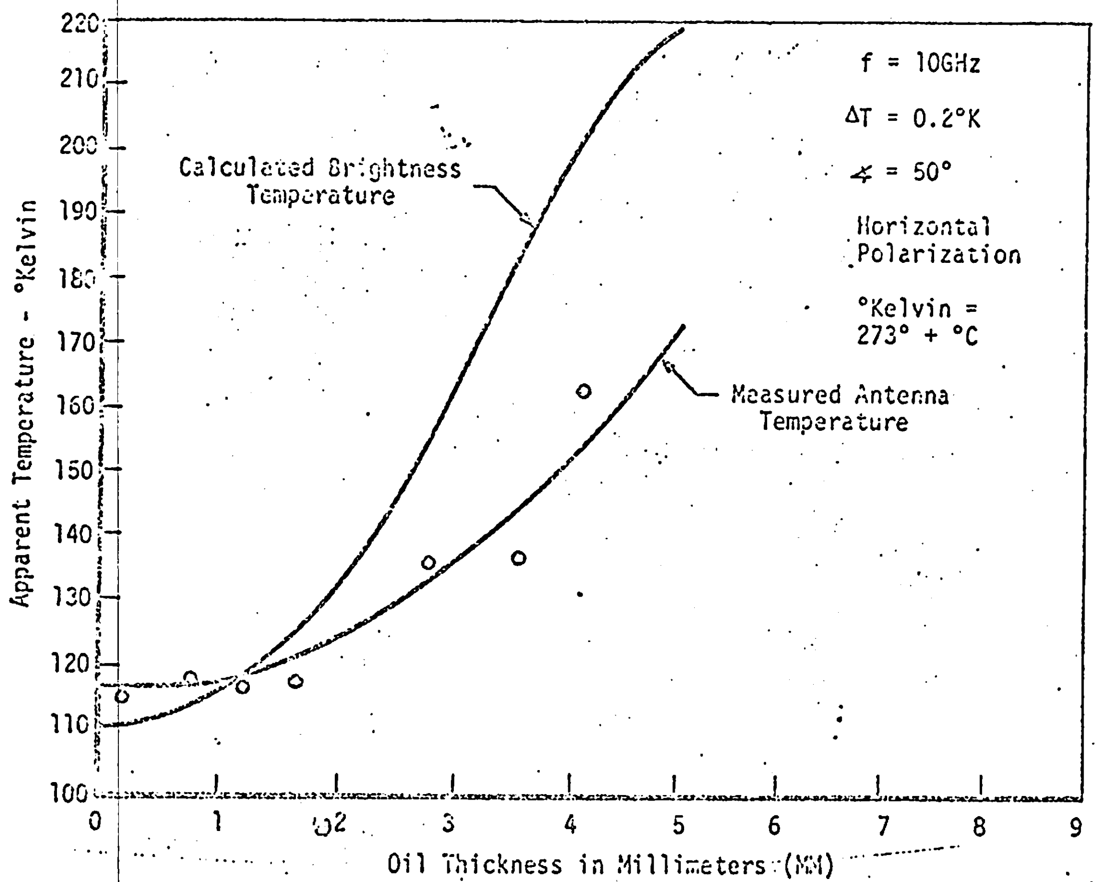

Fig. 5 - 10 GHz Measurement - Horizontal Polarization

014

POPULATION DYNAMICS OF INTERTIDAL ORGANISMS

Joseph H. Connell

Professor of Zoology

William W. Murdoch

Associate Professor of Biology

PROGRESS REPORT

1. Black Abalone on Santa Cruz Island, California

This project was carried on by Miss Mary Bergen, as an M.A. thesis under J. H. Connell. It has yielded some very surprising results.

a. Recruitment. Extremely slow, almost nonexistent, in most areas inhabited by adults. However, young were finally found on the under side of loose stones and shells in nearby quiet bays. Whether these grow awhile there and then move to the "adult" area, we don't know as yet. The smallest ones in the adult area were far back in crevices. We believe that this behavior provides a refuge from predators, such as crabs, snails and octopuses.

b. Growth. Many were marked individually with numbered tags and the shells measured at intervals. Some tags were lost, possibly grazed off, especially from small individuals. Of those abalones which were certainly known, no shell growth has been detected over a period of six months. This indicates either that this was the season when there is usually no growth, or else that these abalones, which were mainly the larger ones, stop growing and probably live a long time afterwards. Recently, some slight growth has begun.

c. Movement. Most marked ones moved very little at all. When sand was washed in, some movement occurred.

d. Mortality. Since tags were known to have been lost, it is impossible to get an accurate estimate of mortality. However, the photographs taken at intervals of the same areas seem to show the same population density. Since there is little recruitment and growth, and little movement, this indicates that mortality rate is also probably very low.

e. Feeding. Observations were made at all tide stages, and Miss Bergen seldom saw any evidence that the abalones were catching drifting algal fronds. Since they don't move much, it looks like they might be getting energy by filtering sea water. Experiments to test this hypothesis have been set up in the marine laboratory. Individual abalones were put in aquaria with filtered sea water (in the dark). Some are being given plankton caught in plankton nets near shore, while others are being starved. They are weighed, wet, at intervals.

Another experiment was set up to see whether abalones can filter out organic matter. Two treatments, with and without abalones have been started. Natural sea water with its contained plankton was put in each, and a sample taken at the start to measure the amount of organic matter present. After an interval, another set of water samples was analyzed to see whether the abalones have filtered some plankton out.

Both of these experiments are in the preliminary stage at present, and no definitive results have been obtained.

f. Effects on other organisms. Estimates of abundances of other intertidal organisms coexisting with abalones are being made. It is then planned to remove abalones from some areas to see what effect this has on the other species.

2. Effects of oil on intertidal grazing animals (several investigators)

In some rocky areas large amounts of oil adhered to the rock surface. In addition, oil adhered to some parts of kelp which was washed up on the shore, although it apparently did not adhere to living kelp offshore.

We attempted to see whether grazing animals ate the oil, and what effect this had on them. Spiny lobsters were placed in seawater in pans, with 3 treatments: a) with crude oil in a tarry lump, b) same, but lump wrapped in plastic screening to prevent the lobster from eating it, and c) no oil. All pans had pieces of plastic screen in as a control for the effect of the screen material. All lobsters died within 12 days and were frozen for later examination.

Black abalones were given kelp (*Macrocystis*), some of which had oil adhering. After a period of feeding they were also frozen. All frozen material is to be sent to Dr. Max Blumer, Woods Hole Oceanographic Institution, for biochemical examination of the fate of ingested oil.

Observations on the shore showed that areas around groups of limpets (*Acmaea*) had little oil. Similar observations in England and France indicate that limpets can rasp off "aged" oil from rocks.

3. Feeding in general marine predators

Experiments with marine predatory snails have recently been completed by Dr. Murdoch. He finds that the snails feeding on two species of mussels prefer certain species regardless of their relative abundances. However, if the 2 prey are equally preferred, such as *Mytilus edulis* and *Balanus glandula*, the predators (*Thais* and *Acanthina*) tend to eat them in the same relative amount as they occur. However, if the predators are trained to eat one species, they then tend to eat a greater proportion of it than it is represented in a mixed population.

Thus, marine predators may "switch" to a more common prey, ignoring the rare species only if they are already trained on the common one, and also show no preference between them.