

Brown Pelicans and the anchovy fishery off southern California

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1. Abstract

Prey-species-diversity for seabirds such as Brown Pelicans (*Pelecanus occidentalis californicus*) is low in the Southern California Bight (SCB). Breeding success and winter populations of Brown Pelicans increase or decrease with increases or decreases in the dominant prey, northern anchovy (*Engraulis mordax*). Availability of anchovies is usually related to their abundance. SCB seabirds could be affected by intensive commercial fishing activities, as has been documented in other areas, such as Peru, South Africa, and northern California. Three viewpoints usually complicate conservation attitudes toward seabird-fishery interactions: (1) they may be viewed as negative competitive impacts by humans on seabirds with resultant population declines of an aesthetic resource; (2) they may be viewed as negative competitive impacts by seabirds on resources of value to people, with economic implications that perhaps call for intentional control of seabirds; and (3) seabirds may be viewed as practical indicators of general environmental "health" or as indicator species of some specific utility in resource management. In the SCB, negative effects of commercial anchovy fishing on Brown Pelican populations remain a potential threat rather than a reality, but fishing impact has been recently suggested by low pelican reproductive rates and breeding population declines at one breeding colony close to an intensive fishery in Mexico. Previous to 1979 both pelican reproduction and fishery catches appeared to fluctuate in relation to anchovy abundance levels. After 1979, despite large increases in anchovy harvest quotas, catches in the US were far below the quota limits. Had quotas been reached, we would have anticipated negative impacts on pelicans and other seabirds on a wider scale in the SCB. To minimize such impacts, we suggest that fishing restrictions at low levels of anchovy abundance will be more effective than restrictions at high levels. Seabird populations would probably be least affected by fishing regulations that avoid prolonged low fish abundance.

2. Résumé

La diversité des espèces de proies disponibles pour certains oiseaux de mer comme le Pélican brun (*Pelecanus occidentalis californicus*) est plutôt faible dans la baie du sud de la Californie (B.S.C.). Le succès de la reproduction et les populations hivernales de Pélicans bruns augmentent ou diminuent selon les fluctuations de leur proie principale, soit l'anchois du Pacifique (*Engraulis mordax*). La disponibilité des anchois est généralement reliée à l'abondance des pélicans au point que la pêche commerciale intensive pour-

rait nuire aux oiseaux de mer de la B.S.C. comme cela s'est déjà produit dans d'autres régions comme le Pérou, l'Afrique du Sud et le nord de la Californie. Trois points de vue différents sur les interactions «oiseaux de mer-pêche» viennent généralement faire obstacle aux efforts de conservation : 1) ces interactions peuvent être considérées comme une intervention concurrentielle négative de l'homme sur les oiseaux de mer avec les déclin de population d'une précieuse ressource qui en découlent; 2) elles peuvent être considérées comme une intervention concurrentielle négative des oiseaux de mer sur certaines ressources utiles à l'homme avec ses répercussions économiques et peut-être aussi les intentions de lutte contre les oiseaux de mer qui s'ensuivent; et 3) les oiseaux de mer peuvent être considérés comme des indicateurs pratiques de «l'état de santé» général de l'environnement ou comme des espèces indicatrices d'une certaine utilité dans l'aménagement des ressources. Dans la B.S.C., les effets négatifs de la pêche commerciale aux anchois sur la population de Pélicans bruns demeurent une menace potentielle plutôt qu'une réalité, mais l'incidence de la pêche a récemment été évoquée par les faibles taux de reproduction du pélican et le déclin des effectifs à une colonie de reproduction située près d'une zone de pêche intensive au Mexique. Avant 1979, la reproduction du pélican et les prises de poissons ont semblé fluctuer selon l'abondance des anchois. Après 1979, malgré l'accroissement considérable des contingents de pêche aux anchois, les prises ont été de beaucoup inférieures aux limites de contingentement aux États-Unis. Si les contingents avaient été atteints, nous aurions pu prévoir des retombées négatives à plus grande échelle sur les populations de pélicans et d'autres oiseaux de mer dans la B.S.C. Pour réduire au minimum ce genre de répercussions, nous supposons que les restrictions de pêche imposées lorsque les disponibilités d'anchois sont plutôt faibles seront plus efficaces que celles décrétées lorsqu'elles sont abondantes. Les populations d'oiseaux de mer seraient probablement moins touchées par des règlements de pêche ayant pour objet de prévenir les périodes prolongées de pénurie des stocks de poissons.

3. Introduction

Several studies on marine birds (reviewed by Ashmole 1971) emphasize food supply as a major factor regulating their populations. This idea has been logically extended by conservationists who ask the question: do intensive (or unrestricted) commercial harvests of important prey species affect marine bird population levels? This leads to another question: how much can an important prey species be harvested without undesirable effects on marine

bird populations? And, finally, what compromises must people and birds make in managed ecosystems?

There are several well-known examples of severe population declines of marine birds in settings of intensive, yield-oriented commercial fishery programs: Peru (Paulik 1971, Idyll 1973, Tovar 1978, Glantz 1979), South Africa (Crawford and Shelton 1978), and perhaps northern California (see Ainley and Lewis 1974). Furness (1978) has modelled a seabird-fish system, and warns of possible detrimental effects of intensive commercial fisheries. Nettle-ship (1977), Brown (1980) and Ainley (1980) have also urged managers of marine resources to give greater consideration to marine birds as components of marine ecosystems, especially where fisheries and seabirds might interact. This is a concern shared by most marine ornithologists.

There are some attempts being made to provide a "forage reserve" within fishery management plans to maintain adequate population levels of prey species for consumers other than people (see Pacific Fisheries Management Council [PFMC] 1978, MacCall 1980, Gress and Anderson 1982).

The Southern California Bight ("SCB" is defined by the Southern California Coastal Water Research Project 1973) provides an opportunity to study fishery-seabird interaction. One can question whether increased harvests of northern anchovy (*Engraulis mordax*) in the SCB would be compatible with present or larger pelican populations. A knowledge of the ecology of the California Brown Pelican (*Pelecanus occidentalis californicus*) breeding in the SCB may provide insight, and management efforts to provide self-sustaining, natural populations of SCB seabirds may benefit from an understanding of pelicans. Attitudes in our society towards interactions between birds and people depend on how abundant seabirds are, the prevailing philosophy of resource use, economic priorities, and which of those views predominate.

Our objectives here will be (1) to review research on Brown Pelicans in the SCB to show the relationships of food supply to changes of certain population measurements (size, breeding performance, survival rates) and compare the related responses of commercial fishing and pelican population parameters to changing anchovy abundance, and (2) to suggest some premises for seabird management based on the data currently available.

4. Responses of birds and the fishery to anchovy changes in the SCB

Anderson *et al.* (1980) have initially examined relationships between anchovies, the fishery, and pelicans. Our discussion here is based mostly on that and subsequent reports (Anderson *et al.* 1982, Anderson and Gress 1983). The SCB may be somewhat unusual in that its diversity of prey for seabirds is reduced over that originally present (see Anderson *et al.* 1982). Pacific sardines (*Sardinops sagax*) along the California and Baja California coast were overfished and became virtually non-existent by the 1950s (see Radovich 1981). Ainley and Lewis (1974) speculated that the failures of some seabird species (e.g. *Phalacrocorax auritus*) along the northern California coast have been due primarily to the lack of sardines. Anchovies have largely replaced sardines as a prey item of Brown Pelicans south of Point Conception (see Anderson and Anderson 1976 and MacCall, this volume), and at present are almost completely dependent on anchovies as a food source during the

breeding season in the SCB (Kelly *et al.* 1981). Pelicans and commercial fisheries in the SCB are also presently taking the same stock and same age-classes of anchovies (Sunada *et al.* 1981). This situation differs from that reported by Randall *et al.* (1981) in South Africa where Jackass Penguins (*Spheniscus demersus*) were found to have consumed a younger age-class of cephalopod than that taken by the fisheries.

In comparing food supply or abundance of a resource to performance by birds or the fishery, many measurements of success can be used, each with perhaps a different biological meaning. Anchovy abundance measurements correlate best with pelican reproductive success on a localized basis that relates, in turn, to young-rearing strategies and colony location (see Anderson *et al.* 1982). Other measurements might relate better to the fishery.

Commercial anchovy harvests are regulated (see PFMC 1978) and should vary according to the total biomass of harvestable resource in the SCB, and this is our basis of comparison here (Fig. 1). Birds and the fishery probably do not respond exactly to the same aspects or segments of a "shared" resource (but see Sunada *et al.* 1981 for the SCB), but for lack of more appropriate measures, we use this common basis. The relationship between this wide-scale measurement of food for pelicans (i.e. area-wide anchovy abundance in the SCB) and abundance of pelicans (Anderson *et al.* 1980) is weaker than that between local food abundance and number of birds. Yet, local levels of food probably often relate to regional levels, because large-scale events are also important influences on the availability of food to seabirds over large geographical areas (see Boersma 1978).

Anderson *et al.* (1980, 1982) have shown that at moderate to high anchovy abundance levels in the SCB, pelican reproductive rates (but not numbers of breeding pairs at the breeding colonies) are correlated with abundance (Fig. 1, but see original references for details). Similar relationships are also believed to exist for other species of seabirds in the SCB such as Western Gulls (*Larus occidentalis*) and Xantus' Murrelets (*Endomychura hypoleuca*) (see Hunt and Butler 1980). The question of mortality and food relationships is now under study, but Anderson and Gress (1983) believe that pelicans are typical seabirds in that mortality rates are more constant than reproductive rates.

Changes in winter populations (when censuses would record mostly resident pelicans) from year to year in the SCB are also related to changes in anchovy abundance in the preceding breeding season (Fig. 2). The pelican population changes shown in Figure 2 were determined from Christmas bird count indices; these are the only long-term data available, but they are believed to be reliable (see Anderson and Anderson 1976). For purposes of our discussion here, we will assume that pelican population status is closely related to food supply, but due to ecological circumstances the relationship is not totally linear. In the SCB, this food supply is highly variable in amount (MacCall 1980). Since it is not diverse, any changes in population of a dominant species (such as the northern anchovy) will have the potential to cause variation in seabird populations, as suggested by MacCall (this volume).

US commercial anchovy catches, at least through 1980, appear to have responded generally to changes in SCB biomass of anchovies (Fig. 3 vs. Fig. 1). Prior to 1978, catch responses seem only weakly related at best to the catch quotas established each year by the California Fish and Game Commission (Fig. 3). The Northern Anchovy Fishery

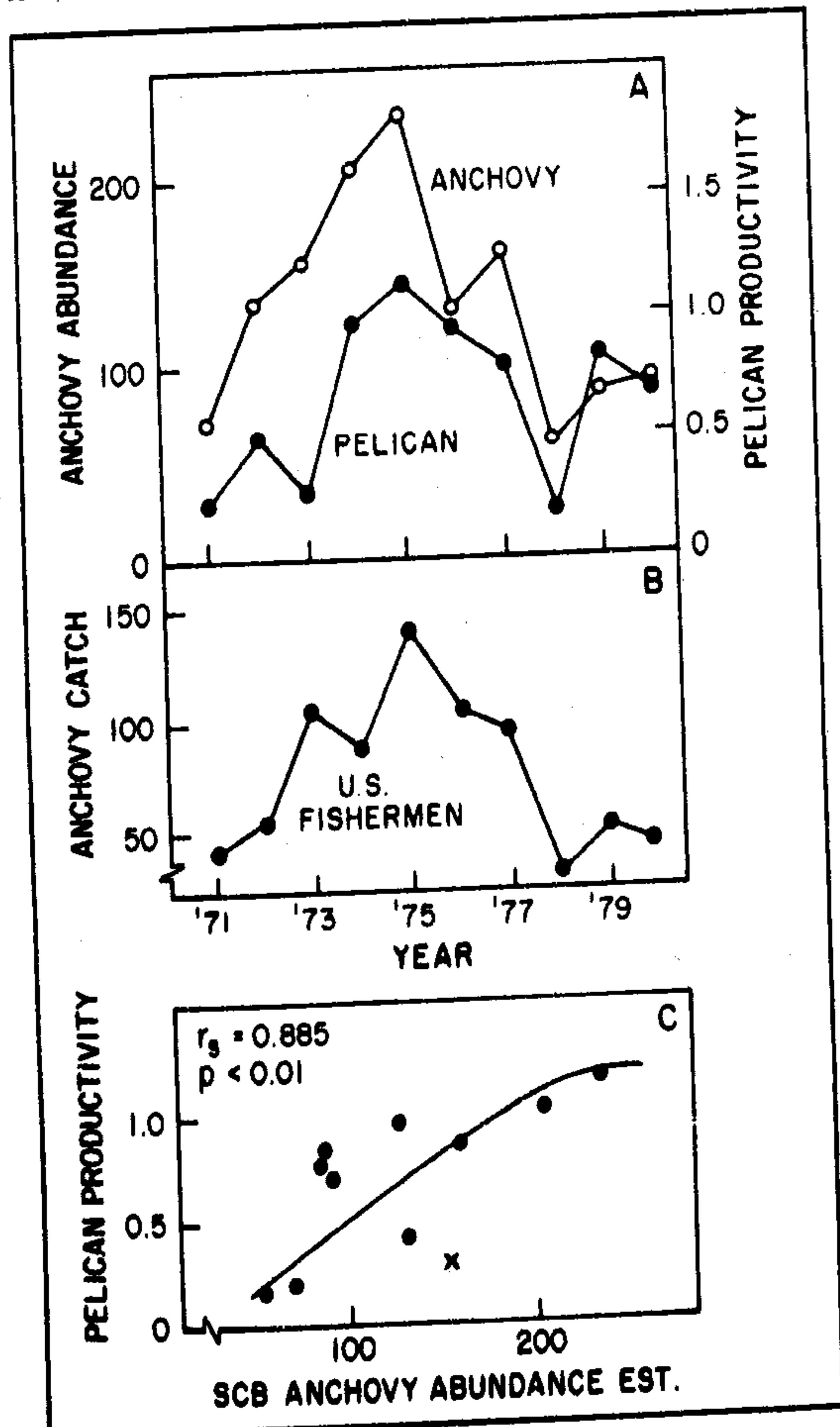
Management Plan, (PFMC 1978), developed according to the Fisheries Conservation and Management Act of 1976, has allowed larger US quotas than previously (Fig. 3).

A complicating and perhaps overriding factor in the fish/person/pelican interrelationship in the SCB is the increasing harvest of anchovies by the Mexican commercial fishery along the northwest Baja California coast. This fishery harvests a large proportion of the same subpopulation of anchovies regulated more conservatively in the US

Figure 1

Patterns of anchovy use by pelicans and the fishery in the SCB.

A. Variations in anchovy biomass estimates (in km² of school surface) and pelican productivity (fledging rates). Anchovy abundance estimates to 1979 are after Mais (1974) and Anderson *et al.* (1982). From 1979 on, biomass estimates are from Stauffer (1980), Stauffer and Parker (1980), and Stauffer and Picquelle (1981), and they are converted to equivalent units based on 1978 comparisons. B. Changes in harvest of anchovies by the US fishery from 1971 through 1980 expressed in metric tons $\times 10^3$ (from Mais 1981). C. Relationship of SCB overall estimates of anchovy abundance (using same units as above) and pelican fledging rates. The curve was fitted by eye. Regional comparisons like this are more imprecise than local ones but they are presented here because they can be directly applied to management units of the anchovy fishery. The "x" represents an anomalous year (1972-73) (see further explanations in Anderson *et al.* 1980, 1982, and Anderson and Gress 1983)



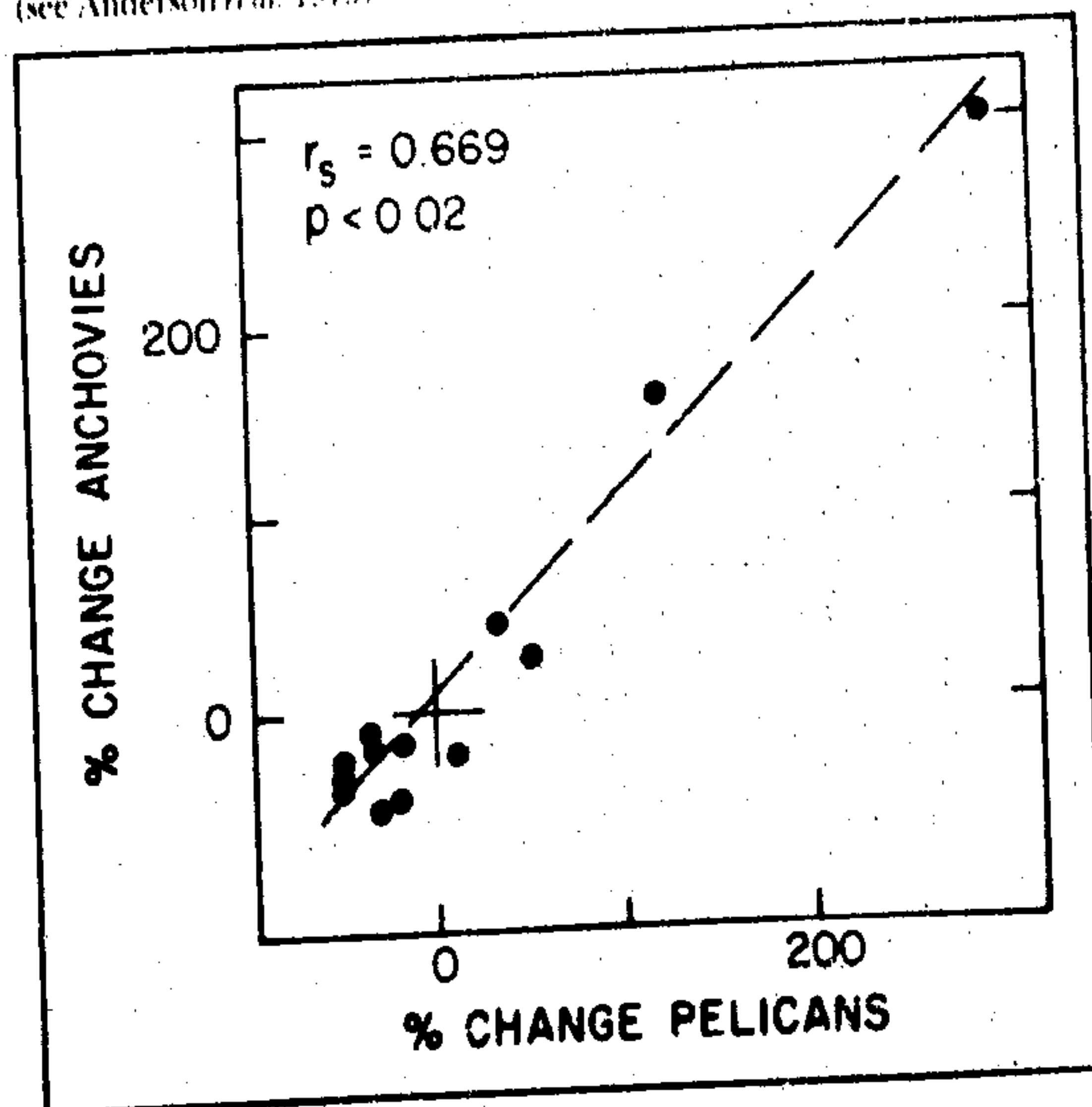
(Fig. 3). In Mexican waters, catches have exceeded those in the US since 1979 (see Mais 1979), largely because the fishery there is unrestricted (Fig. 3); it is a fishery that has probably increased independently of anchovy abundance. Interestingly, signs of deterioration of Brown Pelican reproductive success and breeding populations at the Los Coronados Islands (part of the SCB pelican population; see Anderson and Gress 1983) began in 1979 and continued at least through 1982 (D.W.A. and F.G., field notes). The commercial fishery in Mexico might have significantly reduced productivity and numbers of pelicans and other seabirds dependent on anchovies for the first time in our 14 years of study. That conclusion remains speculative, however, owing to the absence of data showing a precise "cause and effect" relationship.

The drop in US catch (despite increased quotas) has been largely due to economic factors (high cost of fuel, increased processing costs, lack of demand for fish-meal, and increased quotas for the more lucrative Pacific mackerel, *Scomber japonicus*; A.D. MacCall, pers. comm.). Quotas are also more complex than shown in Figure 3; for example, the 1980-81 formula was subdivided as follows: 163 000 total harvest quota by formula, of which 151 000 was for reduction or fish-meal purposes, and of this amount only about 73 000 was allowed by the California Fish and Game Commission for onshore reduction (Stauffer and Picquelle 1981). There is doubt, however, that this final restriction functionally limited the fishery; we cite the example only to illustrate how complex a quota can be.

Recent US catches of SCB anchovies (1978-80) have also contained relatively more young fish. Mais (1981) warns that a "failure" of two age-classes (such as has occurred in the past) could further depress anchovy populations to

Figure 2

Relationship between annual percentage changes in Brown Pelican population indices (from Anderson and Anderson 1976) and annual percentage changes in anchovy abundance (from various sources; see Anderson and Anderson 1976), 1957 to 1970. Due to DDE, pelican population indices from 1971 to 1973 were too consistently low to measure changes (see Anderson *et al.* 1975)



"undesirably low levels." Before they were commercially exploited, anchovies were very scarce at times (MacCall 1980, this volume). Intensive fisheries might increase the frequency of this occurring. We conclude from data obtained prior to 1979 that fisheries in the past had no measurable negative effect on Brown Pelican reproductive success or population. Although potential problems are becoming evident in the SCB's southern (i.e. Los Coronados Islands) Brown Pelican breeding population, US quotas to date seem to have had minimal influence on actual catch, which has responded to availability, and also to market and economic fluctuations.

5. Responses of Brown Pelicans and other species to food

Nelson (1977, 1978, 1979) believes that populations of most tropical and subtropical seabirds are regulated by density-independent phenomena related to variations in food supply. DeMaster (1981) uses the term "resource-dependent" to describe some marine mammal populations, and makes the following claims:

... that many marine mammal populations are probably resource-dependent; that density dependence is a special, and perhaps unusual, case of resource-dependence; that the availability of resources is a function of both density and environmental conditions; that resource-limited populations can decline more rapidly than increase; and that some resource-limited populations are more likely to be found increasing than decreasing or remaining stable.

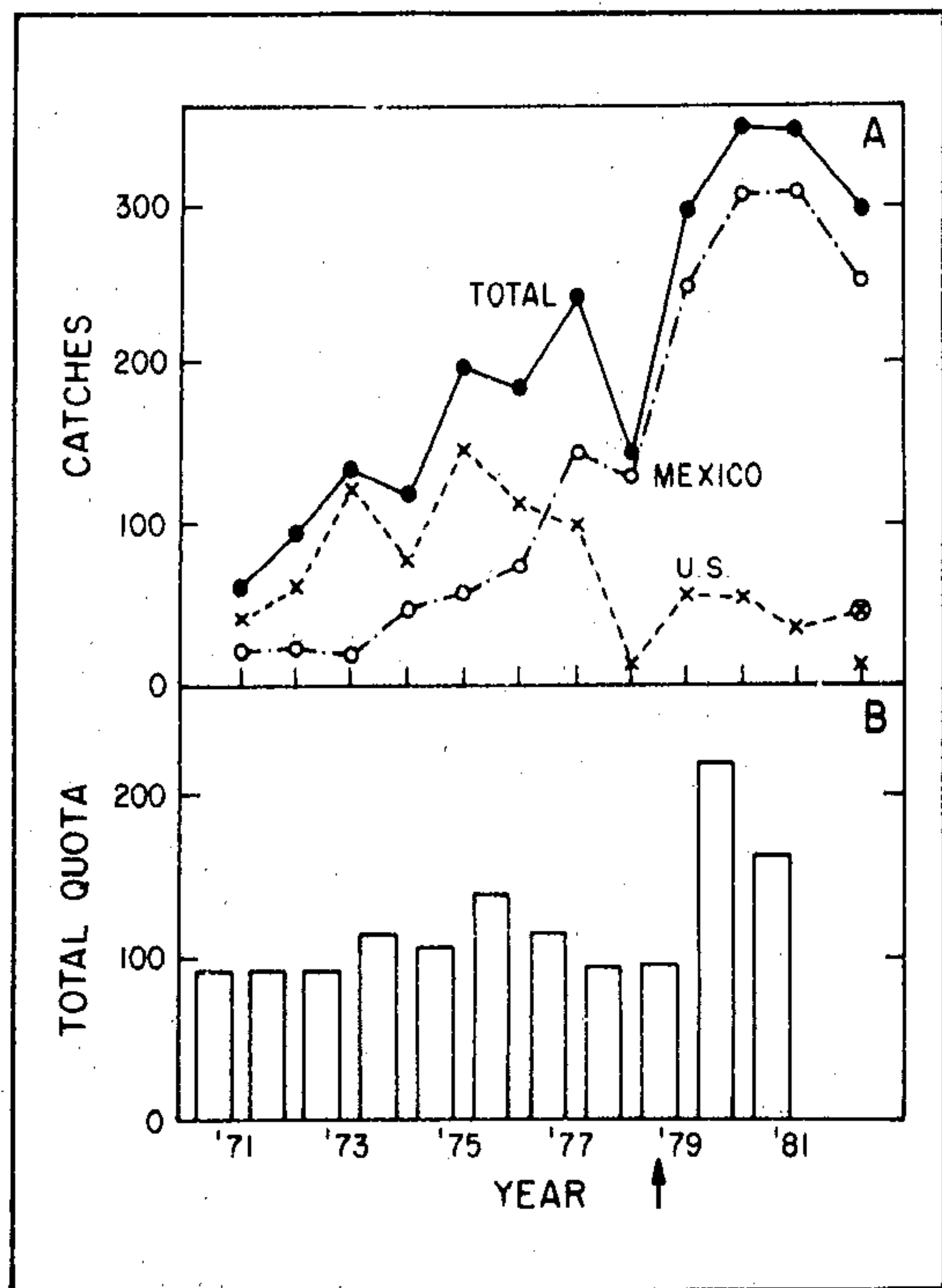
Eberhart (1977) and Estes (1979) in referring to marine mammals have similar suggestions. Marine mammals, however, may differ from Brown Pelicans in that their reproductive rates may be less flexible, since they are usually limited physiologically to one young, which is seldom abandoned. Also, pelicans probably have little or no regulating effect on their food supplies (Anderson *et al.* 1980); this is probably true for all SCB seabirds (MacCall, this volume). All natural predation on adult anchovies may not even have an important effect in regulating SCB anchovy spawning biomass (PFMC 1978) because of the great and dominant variation in environmental conditions of the SCB (MacCall 1980, this volume).

In comparison to marine mammals, pelicans and other seabirds probably have reproductive rates that are more responsive to environmental factors that affect the food supply. This may be the primary population response in seabirds, and one that is more important than compensatory changes in juvenile mortality as in many marine mammals (see Eberhart 1977). Data on Brown Pelicans from the Gulf of California (D.W. Anderson, unpubl.) suggest that juvenile mortality rates are more strongly related to date of hatch and colony synchrony within a given year. Our observations relating to pelicans in the SCB suggest that relationships between food supply and population parameters are similar between pelicans and resource-dependent marine mammals, but that the birds may have more flexibility in responses to food through more variable reproductive rates, and less flexibility in their ability to "integrate" their food supply over time through extensive energy reserves.

Boersma (1978) has shown that the breeding pattern of Galapagos Penguins (*Spheniscus mendiculus*) is closely related to oceanographic conditions (via food availability); she suggested a similar adaptation in Brown Pelicans (*P. o. urinator*) of the same area. In the Peruvian coastal ecosystem, Brown Pelicans (*P. o. thagus*) respond to food shortages with "massive adult mortality and nest desertion" (Duffy 1980). Food-related mortality in adult California Brown Pelicans is very rarely observed (D.W. Anderson, unpubl. data). *P. o. thagus* apparently responds differently to food shortages (which are often extreme) when compared to seabirds in other ecosystems (Duffy 1980); yet high and rapidly responsive reproductive rates are necessarily emphasized in the reproductive strategies of both *P. o. thagus* and *californicus*. SCB Brown Pelicans should logically illustrate a pattern intermediate between *thagus* and more "typical seabirds" because of less extreme shifts between what Horn (1978) terms "profligate breeding and dogged survival."

Brown Pelican reproduction in the SCB populations can also be termed "resource-limited." Food, as an ultimate factor in affecting reproductive rates, is a major source of variation even in the situation of chronic pollution (Keith 1978, Anderson and Gress 1983). One could argue that if

Figure 3
Anchovy catches (A) and various US fishery quotas (B) off southern California. Catches are from Mais (1974) and R. Klingbeil (pers. comm.). Quotas are from Kaneen (1977), Stauffer and Parker (1980), Stauffer (1980), and Stauffer and Picquelle (1981). Values for 1981-82 were projected; the circled "x" represents projected catches and uncircled "x" represents actual catch about half-way through the season. The arrow indicates the beginning of the US management plan (PFMC 1978), which has a Mexican fishery component as part of the recommended quota. Mexican fisheries are not subject to quota restrictions.



reproduction were food-limited and straightforwardly related to food (provided also that no catastrophic events intervene), individual pairs would always attain maximum potential reproduction until they began to affect (deplete) their food supply, with density-dependent competition occurring, or reproduction levelling off as physiological limits were reached. However, we view prey location and capture as a probabilistic process. Pelicans do not go to a "food trough," but rather have a variable probability of detecting mobile prey, depending ultimately on prey abundance and behaviour (availability). Thus, mean prey abundance and/or availability will have some relationship to mean reproductive success for the breeding unit or colony that utilizes this shared food source.

Numbers of Brown Pelicans breeding in the SCB have increased in recent years from the pollution-caused depletions of the early 1970s (Anderson and Gress 1983). Their reproductive rates have continued to reflect the abundance of their prey and their population levels may have done so as well (see previous discussion), irrespective of population level at the time of change in food abundance. With a highly variable carrying capacity (for seabirds reflected through highly variable food supplies), such as is observed in the SCB, pelican numbers should also fluctuate greatly once population recovery from pollution-related catastrophies (see Anderson *et al.* 1975) is complete. However, the variation should also be dampened by the responsive reproductive rates discussed and the tendency for mortality rates to remain stable that is characteristic of most seabirds (see Anderson *et al.* 1982). The fact that pelican populations are serially correlated from one year to the next (see Anderson and Anderson 1976) would tend to further dampen fluctuations that are related to resource-dependent changes in reproduction. As predicted for marine mammals by DeMaster (1981), pelicans might also be in a state of increase more often than decrease. Thus, ideally, we could view the population response of the SCB pelicans in the manner suggested by MacCall (this volume) and Anderson *et al.* (1980) for Brown Pelicans *per se* (Fig. 4): only at the very high and very low populations should one observe clear density-dependence among adults. The usual situation should be that of "phase B" (Fig. 4).

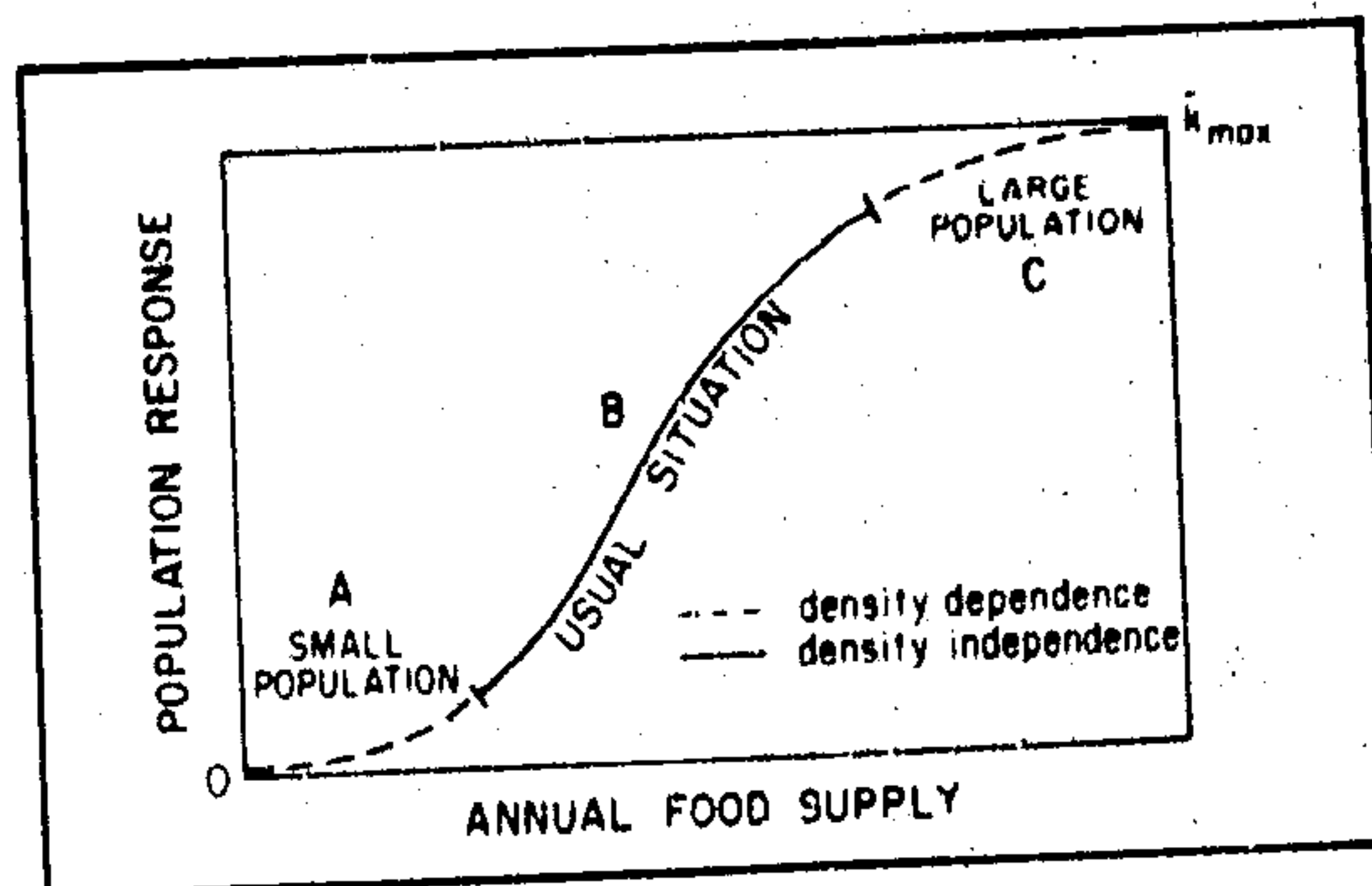
As already seen, pelicans respond to biomass of prey (indirectly through availability) but only to a small geographic proportion of it (Anderson *et al.* 1980). The birds require a much larger prey population size than that actually consumed to produce availability levels in which an adequate ration can be obtained by individual pelicans in the breeding population. One could therefore logically argue that decreases in mean, long-term abundance of the prey base could alter pelican population levels and perhaps even slow or hinder the present recovery of the SCB Brown Pelicans (Anderson and Gress 1983).

6. Conservation awareness toward seabirds

Human attitudes toward familiar seabird species (such as the Brown Pelicans) and subsequent conservation policies are probably influenced by population levels of the birds. Typical human attitudes might vary in relation to the seabird population levels depicted in Figure 4, with the following effects on management policy:

1. At very low levels (A in Fig. 4), density-dependence could become important through lack of such necessities as social stimulation of breeding (see Gochfeld

Figure 4
Idealized short-term seabird population responses (at various initial population levels) to varying levels of food supply. This should not be confused with the logistic growth model



1980), lack of co-operative food finding or, in extreme cases, through the unusual genetic effects in small populations (See Frankel and Soule 1981). At this stage, primary conservation strategy becomes one of preserving genetic diversity. Management of food resources is likely to have relatively less effect than, say, selective breeding, colony protection, artificial feeding, and so on. By this time it might be too late for effective natural population management, in any case.

2. In the linear phase of this idealized response (B in Fig. 4), the target species' population response is probably density-independent, which is typical of the real situation for most population levels most of the time. This situation most commonly involves actions by resource managers. A catastrophic loss of food supplies could suddenly shift the population into density-dependent competition, or other natural or unnatural catastrophies could suddenly reduce populations. In these rare but, given enough time, almost certain instances of catastrophe, about all wildlife managers can do is regroup and reformulate new management policies. Most of the time, however, populations would be expected to remain in the linear range of response, so a management policy based on it should be effective.

Also in the linear range of response (B in Fig. 4), application of the "indicator species" concept has been suggested (Nettleship 1977, Siegfried and Crawford 1978, Ainley 1980, Brown 1980, Anderson and Gress 1981, and others). Sumada *et al.* (1981) have gone so far as to term the California Brown Pelican "a sampling instrument." During our studies, the Brown Pelican has been an "obligate specialist" feeding on a limited-diversity prey base in the SCB. In the Bering Sea, only about 7% of the seabird species are true "specialists" (Ainley and Sanger 1979). Species with limited diets can be useful indicator species if they have only a small or negligible effect on the abundance of their prey. Breeding Brown Pelicans only consume, maximally, an estimated 0.08% of total anchovy spawning biomass (Anderson *et al.* 1980).

A weak relationship between reproductive success of California Brown Pelicans at the two major breeding colonies and overall mean anchovy estimates suggests that pelican reproduction also depends on regional SCB phenomena, particularly oceanographic events. We expect reproductive rates to be a sensitive indicator of local food conditions for pelicans, as has been proposed for other species (see Dorward 1962, Lack 1966:267).

Pelicans may also prove to be indicators of changing environmental conditions, just as other seabirds appear to be in areas off South America affected by large-scale oceanographic events (Murphy 1936, Jordan and Fuentes 1966, Boersma 1978, Duffy 1980). The general relationships seen may provide a way to monitor food abundance (see Anderson *et al.* 1980). Indicator species, no matter what the circumstances that predispose them to qualify, should be ones that respond most rapidly to changes or perturbations for a variety of reasons: ecological, physiological, circumstantial, and so on. Our experiences suggest that the Brown Pelican is such an indicator in the SCB, but whether it would have the same utility under a heavy fishing regime is not known. Once the value of an indicator species is recognized, a paradox arises: the species merits a large degree of protection for its useful qualities, but in order to indicate a deteriorated resource the indicator species itself must deteriorate.

3. Once populations reach a level where environmental factors cause individuals in the population to interfere or compete, another density-dependent phase would occur (C in Fig. 4). Here, conservation may no longer be the issue and "predator control" might be considered. Intentional control of seabirds has never been an issue in the SCB, but unfortunately in other areas predator control is often considered at lower population levels. Such considerations of control and the risks that might be involved are well illustrated by a quote from a report of the Instituto del Mar del Peru (1981):

It must be kept in mind that the assumed product values [fish meal vs. guano] are probably fixed in favor of meal but, far more important, this approach to the matter ignores the threat it presents to the very existence of a bird population that has already reached perilously low levels. Also, the ecological consequences of eliminating the bird populations are not understood. In other animal populations, control of predators has failed to give the expected increase in the prey species, for example, because predation takes more of the diseased individuals, and in their absence disease increases. Until more is known about the interactions between the bird and anchoveta populations, any type of predator control program to reduce the birds would be extremely hazardous.

7. Bird-fishery responses compared

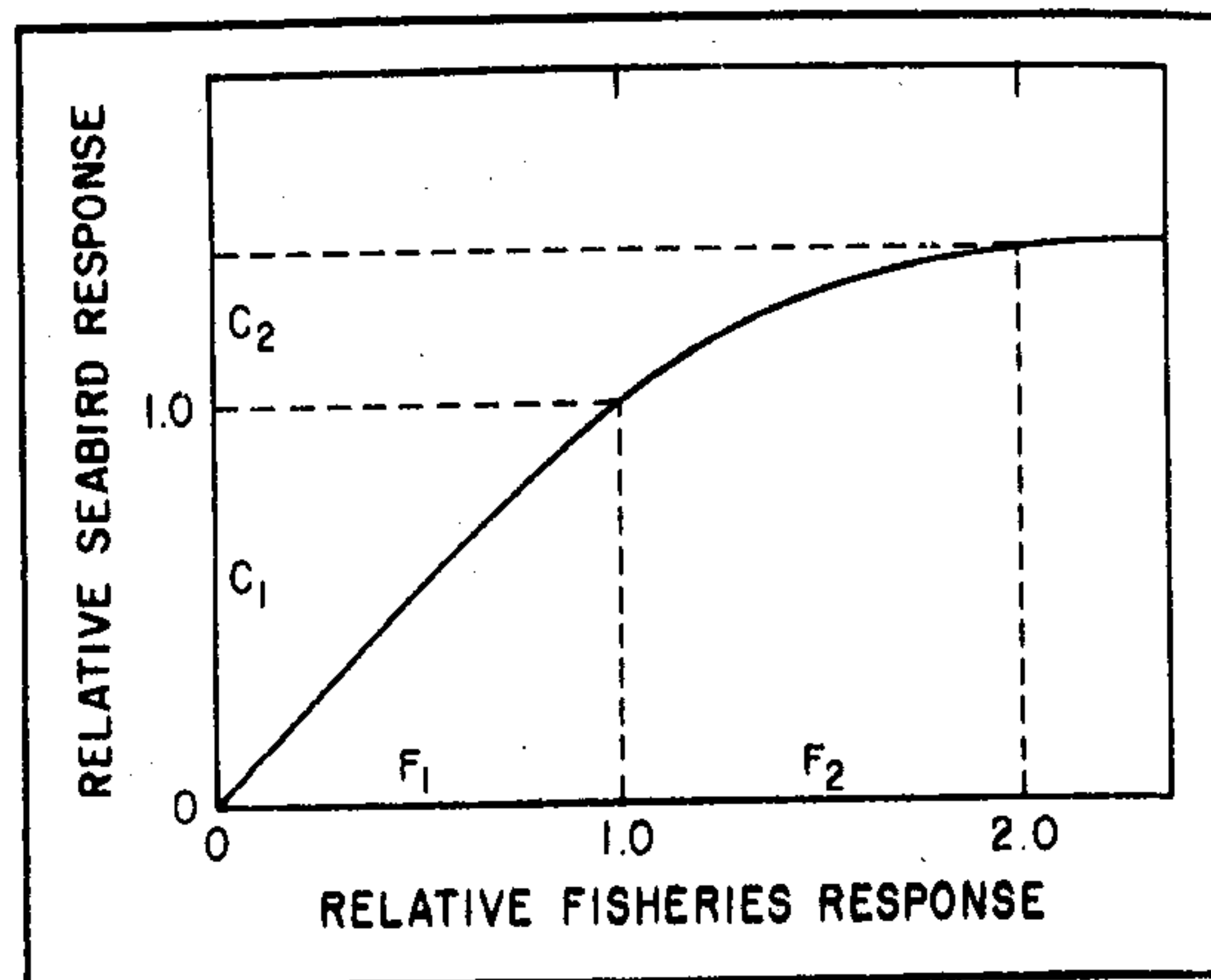
Anderson *et al.* (1980) have discussed the relationship between pelican reproductive rates and anchovy fishery catch (idealized here in Fig. 5) and suggest three possible biological explanations:

1. Both predators are limited by their own asymptotic rates, but birds approach their limit much sooner.
2. The two predators respond to different aspects of fish behaviour that differentially change with fish abundance.
3. There may be direct competition between the fishery and birds, with the fishery being the controlling or more effective competitor (this is the least likely explanation due to the low level of fishing pressure).

If both consumers (the fishery and pelicans) have responded to biomass in the past in an uncompetitive way (pelicans through physical-physiological constraints and the fishery through biomass-oriented regulations and economic

Figure 5

Idealized fishery and seabird responses compared. The curve is based on data taken from Anderson *et al.* (1980) with responses converted to equal units for comparisons. "F" represents the proportional fishing response and "C" the proportional seabird response



profitability, as previously discussed), their relationships might tell us at what point significant person-bird competition might occur. And if pelicans are indicators of environmental condition, then perhaps other seabirds that depend on similar food resources may respond similarly.

We do not interpret Fig. 5 causally, and if birds and the fishery have been responding independently, then restrictions on fishing would have an indirect rather than a direct effect on seabirds. The ratio of pelican to fishery response crudely measures interaction potential: a higher value should indicate a greater differential reaction. From previous discussion (Fig. 4) and by examining the generalized response (Fig. 5), we anticipate that pelicans are most sensitive to variations in food in the linear phase of their response to changing food supplies. In that phase, enhancement of the forage base (such as through fishing restrictions) should be most effective because the ratio of $C_1:F_1$ is maximal. Whereas, at higher anchovy biomasses (assuming still that the fishery is biomass-responsive, such as through regulations), $(C_1 + C_2)/(F_1 + F_2)$ is about 0.7, and the marginal response $C_2:F_2$ is about 0.4. From the viewpoint of seabird conservation in a fishery that is based on a biomass response, a progressive restriction of fishing effort at the lower biomasses, together with fishing closures below a minimum level established as a "forage reserve" (see PFMC 1978), seems potentially most beneficial to seabirds. It follows that larger harvests at higher biomasses should have less effects on seabirds, unless direct competition between the fishery and the birds occurs.

Natural changes in species composition of the prey base of Brown Pelicans and other seabirds in the SCB would lead to different year-to-year interrelationships. This would necessitate responsive management and long-term monitoring of seabirds and their prey.

8. General discussion

Depressions of seabird populations caused by commercial fisheries in systems biologically and oceanographically both similar and dissimilar to the SCB (see MacCall, this volume) were mostly characterized by depressed natality that apparently could not balance mortality related to density-independent phenomena. In fact, it seems likely that seabird species that are resource-limited and long-lived rely on variations in natality (and perhaps also on variations in juvenile mortality) for population regulation. In a highly variable environment, as suggested by DeMaster (1981), such populations would usually be in an increasing phase and dependent on sufficient recruitment to maintain this phase. Thus, severe interactions with a commercial fishery are likely to lead to population depression (MacCall, this volume).

The SCB situation remains encouraging mostly because of the relatively inactive state of the anchovy fishery. We urge continued monitoring of the situation to detect changes in the future. Unusual events such as those off Peru reported by Tovar (1978) and Glantz and Thompson (1981), are known also to occur (but less intensely) in the SCB and nearby areas (Radovich 1961, Anderson 1973). Such natural events which deplete the food supply of resource-limited species of seabirds may have resulted in the evolution of high survival rates and resource-responsive reproductive rates, such as those we observe in Brown Pelicans.

Recovery of the SCB Brown Pelican population from the acute effects of DDT-contamination was more rapid than expected, although it is not as yet complete (see Anderson *et al.* 1975, 1977; Anderson and Gress 1983). The recovery might have been even more rapid were it not for chronic eggshell thinning. Rapid recovery was perhaps due in part to the propensity for such species to recover from reduced population levels mostly through improvements in reproductive rates (Anderson and Gress 1983) once the perturbations were lessened or removed. The rapid recovery certainly attests to the resiliency of seabird populations such as the Brown Pelican.

Managers in the SCB now have a tool for the protection of seabird food resources: the Anchovy Fishery Management Plan and Endangered Species Act (see Gress and Anderson 1982). However politicians can directly decide the actual level of interaction between pelicans and the fishery that will be allowed. Perhaps when more precise natural history data are available, we will be able to anticipate the results of various management options. Recently, new techniques have been developed to better estimate actual biomass of SCB anchovies (Parker 1980). We have used previous anchovy biomass estimates as population indices and measured relative changes. We hope that eventually accurate conversions will be developed to enable better recommendations as to allowable levels of fishing.

For the present, we urge continued monitoring of fish, bird, and other wildlife populations, as well as monitoring of environmental parameters in sensitive areas. For seabirds in particular, conservation involves both the colony (see Anderson and Keith 1980) and habitat at sea. The potential for depression of seabird populations in the SCB through large commercial harvests of anchovies is still a reality in our opinion. Fortunately, resource-limited species such as pelicans seem to be resilient to environmental change.

9. Acknowledgements

We thank A.D. MacCall, D.N. Nettleship, and an anonymous reviewer for criticisms and comment. Our studies were supported by a number of agencies listed in our individual papers cited here.

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