EFFECTIVE AND EQUITABLE DISSEMINATION OF SEASONAL-TO-INTERANNUAL CLIMATE FORECASTS: POLICY IMPLICATIONS FROM THE PERUVIAN FISHERY DURING EL NIÑO 1997–98

KENNETH BROAD[1, 2], ALEXANDER S. P. PFAFF[3] and MICHAEL H. GLANTZ[4]

[1]*RSMAS, Division of Marine Affairs and Policy, University of Miami, 4600 Rickenbacker Causeway, Miami, FL 33149, U.S.A.*
E-mail: kbroad@rsmas.miami.edu

[2]*International Research Institute for Climate Prediction, Columbia University,*

[3]*School of International and Public Affairs, Department of Economics, and Center for Environmental Research and Conservation, Columbia University,*

[4]*Environmental and Societal Impacts Group, National Center for Atmospheric Research*

Abstract. The development of seasonal-to-interannual climate predictions has spurred widespread claims that the dissemination of such forecasts will yield benefits for society. Based on the use as well as non-use of forecasts in the Peruvian fishery during the 1997–98 El Niño event, we identify: (1) potential constraints on the realization of benefits, such as limited access to and understanding of information, and unintended reactions; (2) the need for an appropriately detailed definition of societal benefit, considering whose welfare counts as a benefit among groups such as labor, industry, consumers, citizens of different regions, and future generations. We argue that consideration of who benefits, and an understanding of potential socioeconomic constraints and how they might be addressed, should be brought to bear on forecast dissemination choices. We conclude with examples of relevant dissemination choices made using this process.

1. Introduction

Since the widely publicized crash of the Peruvian anchovy fishery following the 1972–73 El Niño, there has been hope that climate forecasts could permit improved management of fisheries. Knowledge of marine ecosystems and of how they are affected by climate came to be seen as relevant to national economic development issues. The extraordinary 1982–83 El Niño, which influenced climate around the globe, further catalyzed government and scientific interest in developing such forecasting capabilities. A comprehensive environmental monitoring program was put in place in the Pacific Ocean, contributing to improved understanding of the physical mechanisms of El Niño.[1] This led to the development of statistical and dynamical predictive models, as well as multinational programs for applying this newfound understanding to real world problems (see Anderson et al., 1998; Carson, 1998; Agrawala et al., 2001).

Climatic Change **54:** 415–438, 2002.

However, even at the early stages of forecast development, Glantz (1979, 1986) questioned the assumption that a reliable forecast of an El Niño event would necessarily yield significant societal benefit. In particular, he argued that various constraints might limit its usefulness for fisheries management. Such constraints include: variability of El Niño events' intensity and duration; difficulty in translating predictions of sea surface temperatures in the Pacific Ocean into forecasts of fish stocks; difficulty for policy makers and private decision makers in understanding probabilistic climate forecasts; insufficient lead time to undertake mitigating action; and socioeconomic and political pressures on regulators to appease the fisheries industry.

Still, efforts to realize various hypothesized potential benefits of El Niño forecasts have increased throughout the 1990s, supported by claims that an ability to predict seasonal-to-interannual climate variability will result in benefits for society. For example:

> The provision of forecast information in a form that countries can use to benefit their societies is a welcome and exciting way that the wealthier countries of the world can help the poorer countries to help themselves. (World Climate Research Programme 1997, 6-1).

> The ability to anticipate how climate will change from one year to the next will lead to better management of agriculture, water supplies, fisheries, and other resources. By incorporating climate predictions into management decisions, humankind is becoming better adapted to the irregular rhythms of climate. (National Oceanographic and Atmospheric Administration (NOAA) 1994, 23).

Further, growing expectations and the number of groups involved in producing forecasts have led to recent discussions of how best to provide forecasts, including even regulation of forecast dissemination (WMO, 1998). Unlike the 1982–83 event, the 1997–98 El Niño was anticipated, its evolution was monitored, and forecasts of its impacts were globally disseminated through media coverage, numerous workshops, and the internet.[2]

To offer some perspective on this trend, this article draws on observations of the uses and the impacts of El Niño related climate forecasts in the Peruvian fisheries sector during the 1997–98 El Niño. Data limitations make it difficult to prove or disprove Glantz's hypotheses concerning constraints, but we use observations of actual outcomes to highlight conceptual issues that have been largely ignored in efforts to disseminate climate information. While we do believe that forecasts have the potential to provide benefits to numerous groups, we feel that these issues must be addressed if benefits are to be consistently realized.

The current set of providers in Peru of such seasonal-to-interannual climate forecasts includes several multinational organizations,[3] a regional organization based in S. America, four Peruvian governmental agencies and two universities, as well as many individual scientists who distributed forecasts on the web. Many of these providers, albeit to differing degrees, employ the concept of 'societal benefit' in the rationale behind their efforts.[4] The types of information disseminated are of several sorts: (1) real time data of environmental parameters such as sea surface conditions (temperature, winds) and thermocline depth gathered from buoys, ships, and balloons; (2) statistical and dynamic (computer-generated) forecasts of sea surface conditions, precipitation, and temperature anomalies intended for distribution; (3) indices of ENSO phases (e.g., Southern Oscillation Index, Multivariate ENSO Index); (4) experimental forecasts of environmental variables produced for research purposes, but not intended for decision making; (5) qualitative statements characterizing ENSO evolution; and (6) quantitative and qualitative projections of the effect of ENSO on biological and economic variables (e.g., Gross National Product, fishmeal production, agricultural output).

Our ethnographic and archival research, conducted from 1996–1999, suggests that depending on the socioeconomic context, forecast dissemination can have little effect or even what might be viewed as perverse consequences. This analysis contributes to a growing body of evidence revealing theoretical and practical challenges to utilizing climate-related forecast information (see for example Agrawala et al., 2001; Agrawala and Broad, 2002; Barrett, 1998; Glantz, 1995, 1996; Hansen, 2002; Letson et al., 2001; Mjelde et al., 1988; Mjelde and Keplinger, 1998; Orlove and Tosteson, 1998; Pulwarty and Redmond, 1997; Pfaff et al., 1999; Rayner et al., 1999; Roncoli, 2000; Sarewitz et al., 2000). One of the more comprehensive assessments to date is a National Research Council (NRC) report (Stern and Easterling, 1999) that provides an interdisciplinary overview of issues surrounding climate forecast dissemination. It compiles lists of precautionary lessons and recommendations for future research from many sources and cases. Our study is in line with the report's call for direct observation of forecast use in particular settings (1999, p. 3). It also reinforces several of their findings, particularly the identification of constraints on the generation of societal benefits.

While the NRC report is quite general, we draw on a detailed case study. Also, we emphasize the need for an appropriately detailed definition of societal benefit for choosing dissemination policies and better assessing the impacts of forecast provision. We argue that forecast providers must consider what is counted as a desired benefit, among for example labor, industry, consumer, and regional interests today, as well as the interests of future generations. The final section of the article illustrates that even if constraints are known, competing goals should affect forecast dissemination strategies.

We recognize, though, that providers of technical information, such as individual climate scientists, may not feel it their role to study forecast users or the context in which those users operate, and further may hesitate to say which groups' or individuals' benefits should count as contributing to societal benefit. This is understandable for individual scientists, but an approach of the sort suggested above seems imperative for public agencies that fund such research, and for those that promote the dissemination of these scientific findings to address societal needs. Further, any dissemination choice is likely to *de facto* differentially benefit groups within a society. Thus, the issue of who benefits from climate forecast dissemination not only should not, but truly can not, be ignored.

2. El Niño and the Peruvian Fishery

2.1. EL NIÑO

The El Niño-Southern Oscillation (ENSO) is a coupled atmospheric-oceanic phenomenon that has global manifestations and occurs approximately every two to ten years. The oceanographic component of ENSO has been commonly called El Niño. However, in the climate research and prediction community, as well as in the media, El Niño is used interchangeably to represent the ENSO phenomenon and the entire suite of climate anomalies associated with warm phases of ENSO (likewise, La Niña is commonly used in reference to anomalously cold episodes). One effect of El Niño is that water warmer than normal is carried to the surface off the coast of South America (Philander, 1990). For instance, coastal temperatures anomalies as high as 10 °C have been recorded off the coast of Peru (Sharp and McLain, 1993).[5] There have been several El Niño events of varying intensity since the start of the Peruvian industrial fishery, most notably were weak and moderate events in 1957–58, 1965, 1969, 1972–1973, 1986–87, 1991–95, and extraordinarily strong events in 1982–83 and 1997–98.

Interannual climate variations related to El Niño events can shift the spatial availability and relative abundance of the variety of harvested species (Barber and Chavez, 1983; Arntz et al., 1985). In severe events, the increased ocean temperatures and reduced concentrations of phytoplankton negatively impact some pelagic (surface-dwelling) species, such as the commercially important anchovy (*Engraulis ringens*) and sardines (*Sardinops sagax sagax*). Tropical species of fish may extend their ranges, moving closer to the Peruvian coast and south into Chile. As different groups specialize in extraction of different species, this could benefit one group while harming others.

2.2. THE PERUVIAN FISHERY

Fueled by the increased post-World War II demand for fishmeal and the collapse of the California sardine fishery in the 1950s (which made boats and machinery cheaply available for purchase by Peru), the Peruvian industrial fishing boom began in the mid-1950s and lasted until the early 1970s. In the context of weak regulations and technological advances, its catch increased to over 12 million metric tons (primarily anchovy) by 1972, when there was a dramatic decline in the fishery. This collapse has traditionally been blamed on overfishing combined with the 1972–73 El Niño. While both likely played significant roles, there is increasing acceptance of claims that the decline in catch began prior to this moderate El Niño event and was also associated with natural fluctuations in abundance of small pelagic stocks. This is based on mounting evidence that anchovy (genus *Engraulis*) and sardine (genus *Sardinops*) populations fluctuate on multi-year or decadal scales as well as interranual timescales. Furthermore, there are indications of basin wide synchrony in fluctuations of small pelagics.[6] The anchovy collapse in 1973, coupled with political change in the country, led to a temporary nationalization of the fishery, resulting in massive layoffs and restructuring of the industry. It was not until the early 1990s that the anchovy catch recuperated to near pre-1973 levels. This recovery was accompanied by heavy private investment in plants and fishing vessels. Throughout much of the 1990s, the Peruvian fishing sector accounted for over 10% of the world's total fish catch, with over 90% of that going to fishmeal production for export.[7]

The artisanal subsector is made up of small-scale producers who primarily sell their catch to the national market for human consumption. There is tension between the artisanal and industrial subsectors. The former blame large vessels for catching juveniles that are the resource base for the artisanal catch, for impinging on reserved fishing areas when small pelagic stocks move close to shore, such as during an El Niño event, and for coastal pollution resulting from fishmeal processing. Overall, about 200,000 persons are employed in activities connected to these two subsectors. The industrial subsector wields the economic and political power and appears focused on relatively short-term profit maximization (see Thorp and Bertram, 1978; Baltazar, 1979; Zapata Velasco and Sueiro, 1999).

Currently, regulations such as closed seasons (*vedas*) and quotas are made by the Ministry of Fisheries. Its decisions are, in theory, informed by the recommendations of the board of directors of the governmental scientific agency in charge of fisheries and oceanographic studies. In practice, regulations are inconsistently enforced.

2.3. IMPACTS OF 1997–98 EL NIÑO ON THE PERUVIAN FISHERY

Beginning around April 1997, small pelagic fish stocks composed primarily of anchovy moved closer to shore in search of cooler, nutrient rich waters. This led to a dramatic increase in catch that the Peruvian oceanographic agency realized was related to the anomalous warming of the country's coastal waters. Based on this, the Ministry of Fisheries implemented a fishing ban in some areas, but it was retracted just a few days later due to pressure from the fishing industry. The spike in catch vanished rapidly as fish began to migrate both vertically, below the range of the nets, and southward, into northern Chile. The oceanographic agency increased biological monitoring and efforts at coordination with Chilean counterparts. They also recommended intermittent closures of the fishery, but despite protests from some local scientists and from some international agencies, the Ministry enacted special decrees allowing the extraction of non-traditional species, as well as the use of a normally illegal smaller size net mesh to fish traditional species. It is worth noting that despite the anomalous conditions during most of 1997, the massive landings at the start of the event resulted in a relatively high total catch for the year. The solid catch and unexpected high fishmeal prices resulted in a strong profit margin for the fishing industry as a whole (FEO, 1998).

By mid-1998, oceanic conditions slowly began returning to neutral, and fish were concentrated in the few pockets of water supporting the nutrient base for them to feed. Despite the weak stocks, many days of exploratory fishing were permitted. Peruvian regulators, in essence, combined expectations of El Niño's evolution along with intensified sampling and observations, establishing a pattern of flexible management of the pelagic fishery. This balanced the extreme pressures of unemployment, drop in export revenue, and social unrest with the knowledge that without protection of the stressed stocks, a disastrous scenario akin to the 1970s was possible. Overall, though, 1998 production was half that of 1997 (Gestión, 1999), and the heavily indebted industry had difficulty paying interest on loans. Banks were forced to refinance, and many firms went bankrupt. Disruption caused by high unemployment was exemplified by this headline, referring to the largest fishing port, in the country's major newspaper: "Chimbote is a beggar with an ocean view" (Villanueva Chang, 1998).

3. Forecast Value

We assume the *possibility* of a useful, or valuable, climate forecast. This presumes an understanding of what it means for a forecast to have value, or to provide benefits. As this paper considers various conceptual challenges concerning the realization of benefits in particular situations, we first discuss forecast value in general.

Hilton (1981), to some extent synthesizing earlier work, identifies four factors that affect the value of forecast information for decision making: (i) the degree of flexibility to shift decisions; (ii) the payoff function, resulting in a ranking of outcomes (which is affected by many factors, including the decision maker's degree of risk aversion and initial wealth); (iii) the degree of uncertainty in the prior probability distribution over states; and (iv) characteristics of the information-providing system itself, such as its timeliness, or the accuracy of the updated information provided relative to prior information.[8]

Katz and Murphy (1997) build upon such earlier work on the value of information and also provide a useful partial synthesis of a growing economic literature on forecast value. Following this formal literature, they model an agent making a specific decision in two types of situations: first, without the forecast, e.g., in average or normal conditions; and second, with the forecast in question. The forecast might permit better decisions, where 'better' is defined as producing greater expected utility for the agent.[9] Any such increase in expected utility is precisely how the forecast's value to this agent is defined.[10]

Facing this perhaps unfamiliar jargon, it is worth emphasizing the basic point that a decision made using a forecast judged valuable by the expected utility criterion may not in fact raise utility in the future (see the example that helps to define expected utility in note 10; an example relevant to Peruvian fisheries is found in note 12).[11] In short, a valuable (e.g., timely and accurate) forecast whose probabilities dictate Choice A can yield lower future utility if an unlikely event that favors Choice B actually occurs.

Thus even a valuable forecast could be said to be harmful. However, as forecasts are aids to decision making, their value must be assessed at the point when decisions are made, i.e., while there is still uncertainty about the future. Put another way, the forecast should not be judged in light of the random outcome. The quality of a forecast can only be judged over time, when enough outcomes have been observed to allow a judgment about whether using forecasts has yielded plans that have raised utilities on average.

Even when assessing at the decision point, however, a climate forecast could have zero value (and not be worth costly dissemination). Consistent with Hilton (and FN 11) on accuracy raising forecast value, the literature (e.g., Katz et al., 1982) says that accuracy below a 'forecast quality threshold' means that a forecast should rationally be ignored.[12] Thus, it may be that only forecasts of relatively high accuracy actually have value.

Finally, the preceding discussion suggests that forecast value is bounded below by zero, as decision makers will just ignore forecasts possessing insufficient information. Our Introduction implied, though, that forecasts might have perverse or harmful impacts, i.e., have negative value. This apparent conflict vanishes, even within the formal setting of individually rational adoption of only valuable forecasts, when our earlier use of the term harmful is understood to refer to societal rather than individual outcomes. Consider the case when an agent's use of a forecast raises that agent's expected utility, but lowers another agent's expected utility. For instance, in the case of Peruvian fisheries, large firms' reactions to forecasts could hurt artisanal fishermen. Without even considering the many details of aggregating benefits and harms, it is clear that it would be possible to conclude that, on net, reactions to the forecast had harmed the society. Thus, while we assume that net potential societal benefit from a forecast could be sufficiently positive to make worthwhile some efforts to realize benefits through forecast dissemination, we note the need for attention – as within any standard cost-benefit textbook – to which of the members or groups within a society receive those benefits and to which are harmed.[13]

4. Constraints on Realizing Forecast Benefits

In this section, we use examples from Peruvian fishery responses to the 1997–98 El Niño event to identify factors that may limit societal benefits of forecast provision. These constraining factors include both limitations of the climate forecasts themselves (such as timeliness and accuracy, as noted in Hilton's general discussion) and societal constraints on provision of benefits, including: (i) lack of access to forecast information; (ii) difficulties making productive use of probabilistic information; (iii) the stifling of information dissemination and the distortion of informational content; and (iv) various actors' individually optimal reactions to forecasts (e.g., layoffs or increased resource extraction), which may be inconsistent with the provider's view of societal benefit.

4.1. LIMITATIONS OF FORECASTS THEMSELVES

For actors such as fisheries regulators and firms to be able to act confidently to integrate forecasts into planning and operations, the forecasts must contain appropriate spatial resolution for regions of central interest. However, forecasts of the oceanographic aspects of El Niño (primarily sea-surface temperatures) have their greatest skill for two regions far from Peruvian fisheries (specifically, they are in the central Pacific, and are known as the Niño 3.0 region (5° N–5° S, 90°–150° W) and the Niño 3.4 region (5° N–5° S, 120°–170° W)). Further, it is acknowledged that forecasts are of limited skill for coastal areas featuring steep gradients in oceanographic characteristics such as currents and vertical temperature structure. Current forecast skill along the coast does not provide enough detail to proactively manage the inter-regional impacts of climate variability on specific fish stocks, ecosystem processes, or movement of fishing fleets within Peruvian borders. In addition, the collection of observational data for the Peruvian coast, which would facilitate the development of forecasts with greater skill, is limited by a lack of fixed buoys for monitoring conditions and providing input for models.

Forecasts are better at identifying the onset of an event (whether or not an event will occur). However, regulators and firms may also require detailed information regarding the intensity and duration of an event. Knowing the onset can indeed help in planning, but many important fisheries decisions are made after an event has already begun, and as a function of its expected intensity and duration. Public sector decisions of this sort made during the 1997–98 event included readjusting catch quotas and setting closed seasons, while private decisions included stockpiling fishmeal, refinancing loans, and personnel cutbacks. Thus, many management decisions were reactive to trends in catch and biological sampling during the event, rather than proactively based on forecasts.

Even perfect forecasts of climate would not be sufficient for fisheries management, where the focus is not climate *per se*, but rather the implications of climate for current and future generations of fish. The reason is that translating climate predictions into accurate fish-stock predictions raises additional modeling challenges (Parsons, 1996; Masood, 1997; Carr and Broad, 2000). Most models of fish population dynamics do not even use climate variability information, which limits use of climate forecasts for fish management.

The above limiting factors were evident during an international meeting (partially sponsored by the fishing industry and banking sector) held in Lima in October 1997 on the use of climate forecasts to anticipate impacts in different socioeconomic sectors.[14] As it became clearer that forecasts were only of limited relevance for this region's fisheries decisions, the fisheries working group in the end refused to make a public statement.

Finally, it is worth noting that statistical models may inherently generate relatively complex sets of probabilistic information, such as normal probability distributions over a range of future temperature anomalies. Further, from a user's perspective, this underlying uncertainty may be masked within an apparently simple set of published information. For instance, a graph of monthly temperature anomalies may be intended by the scientist as a experimental forecast. The term 'experimental' implies a lack of certainty, but perhaps only to a sophisticated forecast user. And if the graph lacks error bars, then even the most sophisticated user lacks the information regarding the probability distribution.

At the Lima meeting, the miscommunication of complex information was quite evident. Graphics were often copied without original explanatory text as information passed through communications channels. Original disclaimers were lost in the process. In fact, many potential users at the managerial level in the banking and fishing sectors noted a lack of information that would allow them to judge the skill of the forecasts.

4.2. SOCIETAL CONSTRAINTS

4.2.1. *Access*

Assuming that forecast information is of some potential value, forecast providers should be concerned with delivering that information in the appropriate form to target audiences. Even for perfect forecasts, some audiences may have problems of access and/or understanding. In addition to the point that not all groups will understand the provider's native language, it is clear from the 1997–98 event that different audiences (e.g., artisanal, industrial, bankers, and scientists) had different levels of access to the communication technologies such as the internet, fax machines, or short-wave radios, and that this variance in communications led to varying degrees of access to climate forecasts. Simpler technologies may work, but be less timely (which, as Hilton noted, lowers forecast value). Industry managers, for instance, received information via the Internet, while many union leaders did not. Union leaders claimed that if they had had the available information, they would have been able to warn their members of impending layoffs.

4.2.2. *Understanding*

Another limitation may arise from a lack of ability to interpret information that does arrive. Misinterpretation of forecast information has in fact been a serious problem, in particular because, as mentioned above, probabilistic elements of forecasts are often only subtly communicated, and even if so may not be understood. This quote of a forecast made in March 1997, contained in the widely circulated NOAA Experimental Long Lead Forecast Bulletin, illustrates the deterministic and ambiguous language used in forecasts that can facilitate misunderstanding: "Predicts cool east-central Pacific SST weakening to neutral by late spring 1997, becoming warmish by summer/fall/winter 1997–98" (cited in Barnston et al., 1999, p. 32). More generally, various pieces of information were misinterpreted. In two widely publicized instances, real-time satellite images of sea surface temperature were incorrectly interpreted as signals of the rapid demise of the El Niño event, and this information made it onto the front page of a popular Peruvian newspaper (Carr and Broad, 2000). A real-time satellite image that is misinterpreted by local citizens (and even local scientists) may be as ineffective as a bulletin that arrives to a rural village by surface mail two months late.[15]

4.2.3. *Distortion*

Another constraint observed was the stifling and/or distortion of information, including the generation of competing forecasts based on misinformation or misinterpretation. For instance, since poorly paid Peruvian public-sector scientists may consult for private industry, the desire to be valued for private information may create incentives for them to withhold their latest or best information from public release. There were complaints by private citizens that when they called scientists at public institutions with specific questions, they were told that they could hire the scientist if they needed additional information. Additionally, the desire to be well-liked and be respected for their expertise by potential private employers put pressure on some scientists to inject false certainty into scant information; more certain statements may appear more authoritative.

Incentives at firm level may also encourage specific interpretations of uncertain climate data. As witnessed during the 1997–98 event, some fishing firms were awaiting large bank loans and did not wish to highlight the possible severity of an upcoming El Niño event and the increased risk to the bank. In contrast, others wanted to downplay the severity of an event in order to benefit from competitors' bankruptcy, while the firms deep in debt were seeking to have a state of emergency declared to avoid foreclosure. Also, a common perception among government employees and regulators is that scientists may be fired if their recommendations are inconvenient for elites linked to the fishing industry. Thus the media and government scientists were subject to pressure by politically powerful groups to favor certain interpretations of probabilistic forecasts. Generally, these examples raise the crucial issue of individual agents' payoff functions (a factor that Hilton also identified), which will determine their reactions to the forecasts.

Furthermore, competition among public (or non-profit) institutions for limited national and international funds may generate incentives to manipulate information. Peruvian scientific institutions compete to be viewed as the definitive source of information on El Niño. This has resulted in sensationalist statements based less on scientific certainty than on the desire to appear authoritative; e.g., the governmental geophysical institute, during a presentation to the Congress, speculated on the impact of the event on fish stocks, angering the national oceanographic agency. This tendency to sensationalize has been exacerbated by the media itself, who in order to attract attention and sales often turn probabilistic statements into sensationalist, deterministic headlines.

Such behavior raises an important point for external forecast providers such as international agencies: not providing a forecast will not eliminate dubious forecasts. These examples make it clear that if any information is available (even experimental forecasts on purely scientific websites), then some ‘popular forecast’ is likely to be generated by local institutions which have an incentive to showcase their expertise.

4.2.4. *Privately Optimal Reactions*

Additional constraints arise if rational choices by individuals run counter to the outcomes anticipated or desired by forecast providers. One important such reaction is the rejection of a climate forecast or of a set of forecasts. For instance, during the 1997–98 El Niño event, Peruvian decision-makers were exposed to numerous conflicting estimates (for reasons discussed above). This was exemplified by the following headlines that appeared within days of each other in major newspapers (translation by authors): “El Niño may be arriving at its end” (*El Comercio* Jan. 8, 1998) and “The worst of El Niño has not happened, it will occur in next month” (*La República* Jan. 9, 1998).

Faced with this ‘noise’, even President Fujimori allegedly decided to ignore those providing advice, and set up a new commission to advise him on El Niño. In addition, many citizens claimed during focus groups conducted after the event that, had they believed any given projection, they would have acted differently. This suggests that they lost confidence in the joint set of forecasts and, quite rationally, rejected their use.[16]

The noise that can cause decision makers to be reluctant to act upon forecasts of any given event also includes memories of prior El Niño events. For example, people indicated confusion because the 1997–98 event manifested early in the year compared to the last big event of 1982–83, causing uncertainty about how this event would develop. Similarly, some fishermen, firms, and bankers recalled the false starts and finishes of the El Niños of 1991–95, and this made them hesitant to take significant proactive measures (e.g., cancel plans to build new boats and plants, buy new nets, divestment, etc.). Finally, biological indicators which accompanied the 1982–83 event, such as the arrival of massive numbers of jellyfish to the coastal areas, did not occur in 1997–98.

Rejection of forecasts may be reinforced if decision makers are already skeptical of a source of forecasts, e.g., have preconceptions regarding somebody’s credibility and/or an institution’s capacity for producing reliable information. One basis observed for such preconceptions is a previous bad forecast by the institution.

During the 1997–98 El Niño event, one of Peru's most prestigious scientific institutions lost credibility by making several high visibility forecasts early on that there would be only moderate rains in the north of the country instead of the torrential rains that actually occurred.[17] Some banks generally appeared to lose confidence in all forecasting and, acting in a risk averse fashion (again the payoff function matters), decided to stop making loans altogether. Others seemed to ignore the forecasts, and continued making loans as normal.

Other reactions (in addition to rejection of a forecast) may also run counter to the outcomes anticipated or desired by forecast providers. Take fish sustainability as a goal, for instance. If forecasts of upwelling conditions developed from climate forecasts were of sufficient spatial resolution and lead time, industrial fleets might switch locations and thus increase their extractive capabilities, lowering future fish stocks. Firms with sufficient satellite and communications equipment have tried this, and further, during the 1997–98 El Niño, firms increased the frequency and length of trips in expectation of future fishing regulations based on current climate forecasts. Taking instead increasing the welfare of labor as a goal, other privately optimal reactions might be seen as negative from certain social points of view. Given weak labor laws (e.g., no minimum wage during closed seasons), and weak labor unions, management may fire workers in response to a prediction of an El Niño event (at least one firm reported doing this).

5. Societal Benefit and Dissemination Choices

As a result of changes in funding after the Cold War it is increasingly common to justify scientific work on the basis of societal benefits (Pielke Jr. and Glantz, 1995). However, as noted, historically typical mandates such as 'to increase societal benefit' may not be specific enough to distinguish among competing conceptions of benefit, some of which would be served by one forecast dissemination strategy and some by others. Returning to our example, Table I provides one summary of variable conceptions of benefit within the Peruvian fishery as observed during this study; note that each group could be broken into subcategories which themselves may have competing goals. Thus, overly broad mandates may provide inadequate guidance for choosing between different dissemination strategies. Unless it is understood whose welfare contributes to societal benefit, a forecast provider can not even know which dissemination strategies would result in net benefits for society.[18]

For example, providers need some basis for choosing between placing forecasts solely on the internet versus also sending them by radio. Observations of the 1997–98 El Niño event suggest that the former would primarily inform fishmeal plant owners and managers, while the latter would inform union leaders as well. However, radio distribution increases costs.[19] Thus the definition of societal benefit becomes crucial: if labor's welfare is deemed insignificant in the computation of societal welfare or benefit, then radio distribution would not be justified, but if

Table I
Goals of actors in the fishing sector

Group	Goal	Decisions
Industrial purse seine fishers and processors	Large industrial catch, conglomerate profits	Build/repair vessels, change/alter nets, relocate fleet, hire personnel, layoff personnel, install refrigeration system, upgrade plant technology, stop fishing, stockpile produts, change product ratios (fishmeal vs. canning), diversify into other industries
Artisanal fishers (net fishermen, purse seine ($<$30 gross registered tons), longline fishermen, trawlers, divers (shellfish and spearfishermen)	Large artisanal catch, fishing tradition	Change fishing gear, reject non-traditional gear, target new species, change household production options (e.g., spouse works more), negotiate five-mile limit with industry
Labor	High and full employment adequate and stable income	Change household production options (e.g., children sent to work), migration
Banks	Returns on investments	Accept or reject loan request, refinance debt, foreclose
Regulatory administrators and scientists	Sustainable fishery, agency funding, job security, prestige and consulting jobs	Establish closed seasons (*vedas*), establish quotas, gear restrictions/allowances, increase enforcement, increase sampling and observation, permit/reject new licenses, allow experimental fishing, misrepresent skills/information
Conservation groups	Sustainable fishery	Support bans on fishing, lobby for fleet size reduction
Politicians	Re-election, overall welfare	Support regulatory measures, support various constituencies (firm owners, labor)
Media	Sales (subscriptions, advertising)	Exaggerate impacts of El Niño, attribute impacts to El Niño, inject false certainty into information
Foreign interests	Low-cost resource products (e.g., fishmeal), debt repayment	Substitute protein source (soy), structural adjustment policies

Table II
Dissemination strategies based on competing goals and strength of enforcement [a]

	Elected politician's goal: current gross national product	Regulatory civil servant's goal: resource (fish) sustainability
Regulatory power low	Give best forecasts to all	Give only to regulators
Regulatory power high	Give best forecasts to all	Give best forecasts to all

[a] Assumptions for this table: (1) forecasts may enable anticipation of fish location, increased extraction and thus threats to future stocks; (2) some domestic regulators have a goal of resource sustainability (e.g., desire for future fish abundance).

labor's welfare is given significant weight, then radio distribution would be indicated. Providers ignorant of such details of societal benefit, on the other hand, may choose dissemination strategies without regard to their effects. This exposes them to the risk of being seen as having endorsed the details of the actual outcomes, so that *de facto* they have defined which benefits really count.

Here, we demonstrate the importance of the definition of societal benefit through generalized examples of dissemination decisions, based on observations of reactions to forecasts in the 1997–98 El Niño event. At the same time, we still stress the importance of socioeconomic context and constraints. Thus, within scenarios, particular definitions of societal benefit are paired with particular perceptions of socioeconomic constraints. For each pair, a best dissemination choice is suggested, where 'best' means only that in principle it could maximize the defined societal benefit for that scenario (and implies no endorsement by us of any kind).[20] Dissemination choices include: location and local institution with whom to work; target population; whether or not to disseminate; which model(s) to base a forecast on; forecast spatial resolution, lead time, frequency, and medium (e.g., internet versus radio); whether to charge and how much; and whether to train people in interpretation of observations, predictions, and probabilistic forecasts.

Twelve scenarios are presented, with a focus on two types of comparisons: first, for a shift in the definition of societal benefit; and second, for a shift in the constraints on forecast value. Each of these shifts suggests a change in the best dissemination choice.

Consider the upper row in Table II, in which regulatory power is perceived to be low (again, Peruvian fishery regulations have been inconsistently enforced). In the scenario to the left, the goal is maximizing current GNP (consistent with an elected politician's need to point to a strong economy and satisfy the industrial subsector's lobby). Since better information is assumed to permit increased extraction, the forecast provider may wish to make sure everyone has the best forecasts possible,

Table III
Access, education, and prioritization of groups will affect best dissemination strategies [a]

	Labor's welfare matters most	Others' welfare matters most
High access and understanding	Convenient, low-cost dissemination	Convenient, low-cost dissemination
Low access and understanding	Greater dissemination efforts, and education and training	Convenient, low-cost dissemination

[a] Observations relevant to this table: (1) other societal groups (e.g., the industrial subsector) can increase their expected utility without training.

as increased extraction means increased sales and increased current GNP. However, with a goal of resource sustainability (one promoted by various agencies), a provider might choose to give forecasts only to regulators, since low regulatory power implies that if the fishing firms had the forecasts they might seriously threaten future fish stocks.[21] If as in the cell below, though, regulatory power were high, then as long as the regulators get the information, resource sustainability will be enforced, and forecasts may as well go to everyone, for gains from planning fleet maintenance or better investment decisions.

Now consider Table III, lower row. Here the assumption is that labor's (e.g., union) access to and understanding of probabilistic forecasts is low and, implicitly, that others have high access and understanding (echoing the access and understanding observations above). To the right, since what happens to labor is inconsequential for societal benefit, there is no reason for a provider to do anything more than what seems reasonable and convenient, such as putting forecasts on the internet. However, if labor's welfare does matter or, in the extreme, if it is the only thing that matters, then a much different dissemination strategy may appear best. Greater dissemination efforts, such as translating forecasts and broadcasting via the radio, and even training, may be in order. However, if as in the cell above a well-organized union has good internet access and disseminates the information to its members, a provider may rely on lower cost dissemination via the net.

Finally, consider Table IV, the upper row. Here it is perceived that the only forecasts people notice are those of the provider. Also, since legal access to reserved fishing areas can be traded by artisanals to industrials, differing expectations regarding future fish stock locations may lead to trades (as has been observed). If industrials better understand probabilistic forecast information, the winners from trades will tend to be the industrials. Thus, in the scenario to the right, where industrial fishers matter most, forecasts should be disseminated to foster trades. In the scenario where artisanals matter in societal benefit, however, there is a case for withholding forecasts.

Table IV
Which fishers matter most? Do other forecasts exist?

	Welfare of artisanal fishers matters most	Welfare of industrial fishers matters most
Only provider's forecasts exist	Do not disseminate at all	Disseminate to all
Many other forecasts exist	Compete with other forecasts for credibility, and train regarding probabilities	Compete with other forecasts for credibility

Observations relevant to this table: (1) forecasts of changes in coastal fish stocks during El Niño events have relatively low skill; (2) artisanals hold fishing rights to near-shore areas, into which species move during El Niño events; (3) artisanals may sell these fishing rights to industrials (and may do so based on their expectatios); (4) artisanals have less training than industrials regarding interpretation of probabilistic information.

However, the cell below raises an issue that arose during the 1997–98 El Niño event. As myriad forms of forecast information were advanced by a wide range of agents, a provider withholding a forecast was unlikely to leave any decision makers in a forecast-less state. Thus, the provider may wish to disseminate, and even to compete to make its information heard above the din. Further, in order to make its probabilistic statements better understood by all, it may wish to offer some training in forecast interpretation.

6. Discussion

This paper has presented a number of findings that are in keeping with both Glantz's conceptual challenges raised in the 1970s and subsequent elaborations (e.g., Stern and Easterling, 1999). In short, even a skillful forecast may be limited by a range of societal constraints. Since Glantz made his points, two decades of intensive physical science research have yielded increases in the ability to forecast aspects of El Niño events. In marked contrast stands the paucity of socioeconomic study of the effects of climate variability, or of the uses of climate forecasts in specific locations and sectors.

Attempting to address the stated need for real cases, we have based our comments upon observations of reactions in the Peruvian fishery to the 1997–98 El Niño event, and to the many forecasts of the event. We have argued two things in particular. First, an understanding of the constraints on forecast value and how they might be addressed is necessary for best dissemination choices. Second, an appropriately detailed definition of societal groups, and ideally also of each group's benefits and costs, is equally necessary.

Placing these points in a broader context of choices faced by climate research and dissemination institutions, first note that forecast provision has been used here to mean almost any provision by any individual or institution of almost any form of climate information. This relatively loose use of terms avoids an additional discussion of the following: which among the set of more precisely defined forecasting approaches might generate the greatest societal benefits or value? For instance, forecasts based upon an enhanced ocean and biological monitoring program, i.e., not solely upon coupled ocean-atmosphere models, may be more appropriate for some fishery decisions. A second issue is exactly which type of forecasts should be widely disseminated. We noted above that users often face a dizzying array of forecasts from different sources. As evident during the 1997–98 El Niño, someone searching the Web may be as likely to find an experimental prediction from an unvalidated model as a forecast that takes into account several models and local climatic conditions besides El Niño. This raises a question as to whether there should be some sort of quality control or uniform method of validation for information distributed by public agencies, as occurs with weather forecasts and is currently under discussion with respect to seasonal-to-interannual climate forecasts. Results intended for sharing with colleagues could be password protected, for instance, while forecast products which have been approved by the community through a consensus process could be distributed more widely by a limited number of specialized organizations.[22]

Third, beyond simply increasing access to information, some constraints that exacerbate inequity in the use of climate information could be partially minimized through targeted training of various end users of information. For instance, basic education on understanding climatology of a region, and in interpreting probabilistic information expressed in graphics would aid a range of decision makers in the fisheries, banking, and media sectors by allowing them to better judge for themselves the trustworthiness of information sources, to distinguish observations from model outputs, and to decide for themselves the potential impact of a forecasted event on their activity of interest. Such a broader understanding of climate would also increase the ability to develop anticipatory mechanisms that enhance societal resilience to all sorts of climate variability, reducing reliance on short lead time forecasts.

Additional choices loom here as well. For example, another option is to train those at scientific institutions to better communicate with the media to lessen the chance of misinterpretation in the flow of information to the public. Alternatively, advanced training on useful modeling of the relationship between environmental and biological variables could help agencies charged with providing advice for fisheries management.

Fourth, broadening beyond fisheries, policy makers may also need to choose where to focus among sectors. It is quite possible that using forecasts to manage fisheries would be given a low priority among all sectors, particularly if it turns out to be relatively difficult to use forecast information to achieve societal benefits there. The necessary information for fisheries management involves modeling complex ecosystem interactions, a more daunting scientific challenge than, for instance, most stream-flow modeling needed for the water management sector. On the social side, understanding private firm decisions in the fisheries sector is an unavoidable challenge, while other sectors may have fewer private firm interests. There may be more common shared values regarding collective action for disaster prevention and response, despite alleged issues of corruption and political favoritism, while antagonistic groups in the fishery sector may share fewer values. Also, many technological fixes in civil defense are relatively straightforward compared to fisheries management.

Comparing Peruvian sectors for the 1997–98 event, proactive disaster management based on advanced warning appears to have kept the loss of life and property damage lower than during the 1982–83 El Niño event (Zapata Velasco and Suiero, 1999; Zapata Velasco and Broad, 2001). For the fishery, unprecedented measures by the regulators to protect the anchovy stocks were taken once it was indisputable that a major El Niño was underway. Nonetheless, provision of forecasts did not prevent: (1) massive labor disruption; (2) increased illegal fishing; and (3) a short-term biological, as well as apparently lasting economic decline of the industry. Again, different sectors face different challenges.

Nonetheless, our points about a best approach to forecast dissemination choices based on fisheries sector observations seem generally applicable. Further, we argue that not only dissemination but also training, research and development choices should be considered in this way. For example, those who generate forecasts must choose whether to focus their research on a long time scale, or on increased temporal and spatial resolution for a short time scale. If short-term profits define benefit, the latter might be preferred, whereas if sustainability is the goal, an improved forecast of long-run stock dynamics might be best.

Also, for both dissemination and research and development choices, these points should apply to other regions and other sectors as well. Other South American and Pacific Rim countries experience El Niño impacts on fishing (see, e.g., Lehodey et al., 1997), and other sectors in Chile, Colombia, Ecuador and Peru are also directly impacted by climate variability. Our points regarding constraints and benefits definition seem likely to be relevant to applications of forecasts to agriculture, disaster prevention, water resource management, and health.

Acknowledgements

This paper resulted from a multi-disciplinary project at the International Research Institute for Climate Prediction (IRI). Individual authors gratefully acknowledge additional support from the Columbia Earth Institute, NOAA-OGP, NSF, the Tinker Foundation, and the Research Institute for the Study of Man. We also wish to thank Shardul Agrawala, Bob Blaisdell, Mary-Elena Carr, Amy Clement, Pilar Cornejo, Heidi Cullen, Dale Jamieson, Dave Letson, Nate Mantua, Mike McPhaden, George Philander, Donald Pfaff, Dennis St. George, Ed Sarachik, Richard Seager, Caitlin Simpson, Stephanie Strickland, Steve Zebiak, and anonymous reviewers for helpful comments on earlier drafts.

Notes

[1] Notable efforts included the Coastal Upwelling Ecosystems Analysis (CUEA), which was being carried out off the Peruvian coast when the 1972 El Niño event took place, the North Pacific Experiment (NORPAX) in the early 1970s, whose objective was to improve prediction of climate and weather for the Pacific Ocean and North America, and the multinational Tropical Ocean Global Atmosphere Program (TOGA), which ran from 1985 to 1994 and collected crucial environmental data for understanding the evolution of ENSO.

[2] Certain terms used in this paper may appear to imply a precise definition where no such consensus exists. See Aceituno (1992), Philander (1998), and Trenberth (1997) for debates on defining what an 'El Niño' event involves. Another example is the term 'forecast'. Some would distinguish among forecasts, predictions, and observations, although our study in Peru indicates that those receiving these different types of information do not always perceive such distinctions. Thus our use of the term 'forecast' includes primary prediction products produced by atmospheric scientists, customized forecasts for specific areas and sectors, as well as forecasts of El Niño's evolution based on real-time observations of the climate system. We use the terms forecast and prediction interchangeably.

[3] Organizations most active in the global dissemination of climate information during the 1997–98 event include the World Meteorological Organization, the International Research Institute for Climate Prediction, NOAA, and NASA.

[4] As exemplified here by the World Climate Research Programme: "Scientific Rationale: ... countries and regions have learned to use what predictive skill the forecast offers for applications to agriculture and water resources. They have generally found the results especially useful – indeed having major societal benefit" (1997, 6-1).

[5] For an overview of the effects of the 1997–98 El Niño on physical mechanisms and biogeochemical cycles, see McPhaden (1999) and Chavez et al. (1998).

[6] See Kawasaki et al. (1991), Lluch-Belda et al. (1992), Sharp and Csinke (1983), Sharp and McLain (1993) and Bakun (1996).

[7] Coastal upwelling regions associated with the Eastern Boundary Current (which include the Peruvian coast) account for 0.1% of the world ocean, yet account for 5% of global primary production and 17% of global fish catch (Pauly and Christensen, 1995).

[8] Hilton's main point is that there is no general monotonic relationship between the value of information and attributes of decision settings and decision makers, such as flexibility, risk aversion, initial wealth, or initial uncertainty. In contrast, changes in the attributes of information systems noted above, like accuracy, do consistently affect information value.

[9] For a given future action, expected utility is an estimate of how well off one will be if that action is taken regardless of the future state (e.g., rain or sun). It is calculated as a weighted average, most precisely the sum over all possible future states of how well off one will be in each state times the actual probability of that state. Thus, if we say that expected utility is raised by a change in action that is based on an accurate new forecast of a 90% chance of sun (versus the historical 50% chance), that means that given the new accurate probabilities the weighted average for the new action, e.g., driving to the beach, is higher than that for the old action, e.g., staying home. This does *not* mean the actual utility will be higher in the future with the new action. In the unlikely event (10%, as the 90% chance of sun is true) of future rain, the stay-home plan will actually yield more utility.

[10] An additional complication arises if the forecast's probabilities are not actually correct. Users' actual expected utilities should be calculated with actual probabilities. However, when users do not have this information, they will use the best information they have to estimate their actual expected utility for a given action. That information could be just the historical probabilities, or be from a forecast if one is used (FN 13 on non-use). With probabilities closer to the truth than historical ones or those of previous forecasts, improved forecasts have value in this case, for better estimates of actual expected utility. Also, low-quality forecasts with probabilities very different from the actual ones, but that people believe provide correct probabilities, can clearly be harmful if used for decisions.

[11] Consider the decision to purchase a new, more efficient fishing boat which lasts 10 years, and assume this would increase expected utility given historical probabilities of fish catch. Then assume that a timely and accurate forecast puts high probability on low catches for the next ten years. Given these probabilities, not purchasing the boat yields higher expected utility. However, normal catches in the next ten years are still possible, if unlikely. If they occur, future utility without the boat will be lower than it would have been with the boat (which would have been purchased had there not been a forecast).

[12] The threshold is just the accuracy below which information does not permit agents to raise their expected utility. This threshold may be quite high, i.e., a forecast may have to be quite good to be useful. For instance, Walters (1989) suggests that the short-term fish stock recruitment forecasts that explain less that 60–80% of the variance be ignored.

[13] Note that here we are just re-stating one of our two main points from the Introduction, albeit in the cost-benefit context. That is, however formally or informally they aggregate benefits, any agencies facing the challenge of dissemination should bring to bear on their choices an appropriately detailed definition of societal benefit, or at least a reasonably detailed conception of groups within society. Without that type of judgement, about who is distinct from whom and who matters and how, it is impossible to know if individually rational adoptions of forecasts, even if they do help the adopter, will yield societal gain.

[14] 'Is This the El Niño of the Century?', held in Lima, Peru, October 28–30, 1997.

[15] Thus, lack of timeliness and low accuracy through misinterpretation can both greatly lower information value. This comment on provision systems is consistent with Hilton.

[16] In Murphy's language (Chapter 2 of Katz and Murphy (1997)), a surfeit of varied public forecasts may cause users to perceive the set of forecasts as 'no more than noise'. Thus, users' personal probability distributions over events have extremely high variances, e.g., positive weight on a great number of widely varied outcomes. This diffuse distribution, intuitively judged to be unhelpful, would in Murphy's terms lack 'sharpness', i.e., one of the elements of forecast quality (the highest quality forecasts are perfectly sharp and unbiased, i.e., have probability one on the truth).

[17] See http://www.igp.gob.pe/enero.htm for the forecast and discussion of methodology and Zapata Velasco and Suiero (1999) for details on dissemination of this forecast.

[18] This type of judgement regarding whose welfare counts is not a technical issue that can be derived from a particular formal or technical economic approach (such as discussed in Section 2). At a societal level, it is purely a matter of equity or political philosophy, and surely different persons and groups will have their own views. Our emphasis is that any argument for a policy choice will

implicitly include such judgement. Also, making the need for such judgment explicit may allow more voices to be heard concerning choices. Note that the need for an input of judgement does not preclude use of technical approaches to decision analysis such as cost-benefit analysis, that formally aggregates net benefits across individuals. There, the judgement often takes the form of an explicit social welfare function, which provides as an input to the analysis the weights to use in the aggregation.

[19] While costs will increase (in particular when multiple dialects are involved), and while even small costs may seem large when budgets are small, some might argue that the cost increase would be minimal. If so, it remains to be explained why radio distribution does not occur. If there are indeed benefits as we have argued, then it would seem that some form of costs, perhaps even simply organizational costs, discourages the use of radio when it could help. But perhaps it is simply that people do not care about those who would receive only the radio broadcasts; that would explain the lack of beneficial broadcasts. If so, though, then the story just exemplifies what we discuss here, the importance of whose benefits count.

[20] Our scenarios have relatively narrow definitions of societal benefit, i.e., quite focused objectives. Real policy makers may well need to address multiple objectives (our narrow definitions here are for pedagogical clarity). The likelihood that difficult tradeoffs among a complex set of objectives is a real challenge for policy makers is in keeping with our point that shifts in the definition of benefit (e.g., from some political swing) or the details of constraints will likely imply a change in the 'best' dissemination choices.

[21] See Table IV for more on the issue of conditions under which withholding might work.

[22] The International Research Institute for Climate Prediction and the European Centre for Medium Range Weather Forecasting limit access to many of their forecast products.

References

Aceituno, P.: 1992, 'El-Niño, The Southern Oscillation, and ENSO – Confusing Names for a Complex Ocean Atmosphere Interaction', *Bull. Amer. Meteorol. Soc.* **73**, 483–485.

Agrawala, S. and Broad, K.: 2002, 'Technology Transfer Perspectives on Climate Forecast Applications', *Research in Science and Technology Studies* **13**, 45–69.

Agrawala, S., Broad, K., and Guston, D.: 2001, 'Integrating Climate Forecasts and Societal Decision Making: Challenges to an Emergent Boundary Organization', *Science, Technology, and Human Values* **26**, 454–477.

Anderson, D. L. T., Sarachik, E. S. et al.: 1998, 'The TOGA Decade: Reviewing the Progress of El Niño Research and Prediction', *J. Geophys. Res.* **103**, 14167–14510.

Arntz, W. E., Landa, A., and Tarazona, J.: 1985, 'El Niño: Su Impacto en la Fauna Marina', *Bol. Inst. Mar.*, vol. ext., Perú-Callao, p. 222.

Bakun, A.: 1996, *Patterns in the Ocean: Ocean Processes and Marine Population Dynamics*, California Sea Grant College System, p. 323.

Baltazar, C. M.: 1979, *Estado, Pesca y Burguesía: 1939–1973*, Realidad y Teoría, Lima.

Barber, R. T. and Chavez, F. P.: 1983, 'Biological Consequences of El Niño', *Science* **222**, 1203–1210.

Barnston, A. G., Glantz, M. H., and He, Y.: 1999, 'Predictive Skill of Statistical and Dynamical Climate Models in Forecasts of SST during the 1997–1998 El Niño Episode and the 1988 La Niña Onset', *Bull. Amer. Meteorol. Soc.* **80**, 217–243.

Barrett, C. B.: 1998, 'The Value of Imperfect ENSO Forecast Information: Discussion', *Amer. J. Agric. Econ.* **80**, 1109–1112.

Bjerknes, J.: 1966, 'A Possible Response of the Atmospheric Hadley Circulation to Equatorial Anomalies of Ocean Temperature', *Tellus* **8**, 820–829.

Broad, K. and Agrawala, S.: 2000, 'The Ethiopia Famine: Uses and Limits of Seasonal Climate Forecasts', *Science* **289**, 1693–1694.

Carr, M.-E. and Broad, K.: 2000, 'Satellites, Society, and the Peruvian Fisheries during the 1997–1998 El Niño', in Halpern, D. (ed.), *Satellites, Oceanography and Society*, Elsevier Science B.V., Amsterdam, pp. 171–191.

Carson, D. J.: 1998, 'Seasonal Forecasting', *Quart. J. Roy. Meteorol. Soc.* **124**, 1–26.

Castillo, J.: 1998, El peligro de El Niño no ha pasado, lo peor ocurrira en el próximo mes. *La Republica*. Lima: 3 (9 Jan).

Chavez, F. P., Strutton, P. G., and McPhaden, M. J.: 1998, 'Biological-Physical Coupling in the Central Equatorial Pacific during the Onset of the 1997–1998 El Niño', *Geophys. Res. Lett.* **25**, 3543–3546.

Deser, C. and Wallace, J. M.: 1987, 'El Niño Events and their Relation to the Southern Oscillation: 1925–1986', *J. Geophys. Res.* **92**, 14189–14196.

El Comercio: 1998, El Niño puede estar llegando a su fin. Lima, 8 Jan, p. 1.

Glantz, M. H.: 1979, 'Science, Politics, and Economics of the Peruvian Anchovy Fishery', *Marine Policy*, July, 201–210.

Glantz, M. H.: 1986, 'Man, State, and Fisheries: An Inquiry into some Societal Constraints that Affect Fisheries Management', *Ocean Development and International Law* **17**, no. 1/2/3, 191–270.

Glantz, M. H. (ed.): 1995, 'Usable Science II: The Potential Use and Misuse of El Niño Information in North America', A Workshop Report, Environmental and Societal Impacts Group, NCAR, Boulder, CO, 1994, p. 260.

Glantz, M. H.: 1996 (2001), *Currents of Change: El Niño's Impact on Climate and Society*, Cambridge University Press, p. 194.

Gestión: 1999, Producción pesquera cayó 50.8% en 1998. Lima, 10 January, p. 17.

Hansen, J. W. (ed.): 2002, Special Issue on Applying Seasonal Climate Prediction to Agriculture. Agricultural Systems, in press.

Hilton, R. W.: 1981, 'The Determinants of Information Value: Synthesizing some General Results', *Management Science* **27** (1), 57–64.

Katz, R. W., Murphy, A. H., and Winkler, R. L.: 1982, 'Assessing the Value of Frost Forecasts to Orchardists: A Dynamic Decision-Making Approach', *J. Appl. Meteorol.* **21**, 518.

Katz, R. W. and Murphy, A.: 1997, *Economic Value of Weather and Climate Forecasts*, Cambridge University Press, p. 222.

Kawasaki, T., Tanaka, S., Toba, Y., and Taiguchi: 1991, 'Long-Term Variability of Pelagic Fish Populations and their Environment', *Proceedings of the International Symposium*, Sendai/Japan, Pergamon Press, 14–18 November, p. 402.

Lehodey, P., Bertignac, M., Hampton, J., Lewis, A., and Picaut, J.: 1997, 'El Niño Southern Oscillation and Tuna in the Western Pacific', *Nature* **389**, 715–718.

Lluch-Belda, D., Schwartzlose, R. A. et al.: 1992, 'Sardine and Anchovy Regime Fluctuations of Abundance in Four Regions of the World Oceans: A Workshop Report', *Fisheries Oceanography* **1**, 339–347.

Masood, E.: 1997, 'Fisheries Science: All at Sea when it Comes to Politics?', *Nature* **386**, 105–106.

McPhaden, M. J.: 1999, 'Genesis and Evolution of the 1997–1998 El Niño', *Science* **283**, 950.

Mittaine, J. F. (ed.): 1998, Proc. from Fishmeal Exporters Organization Annual Conference, Puerto Rico, 16–17 November, Fishmeal Exporters Organization, p. 69.

Mjelde, James W. and Keplinger, K.: 1998, 'Using the Southern Oscillation to Forecast Texas Winter Wheat and Sorghum Crop Yields', *J. Climate* **11**, 54–60.

Mjelde, J. W., Hill, Harvey S. J., and Griffiths, John F.: 1988, 'A Review of Current Evidence on Climate Forecasts and their Economic Effects in Agriculture', *Amer. J. Agric. Econ.* **80**, 1089–1095.

NOAA: 1994, El Niño and Climate Prediction. Reports to the Nation on our Changing Planet. Spring 1994, 1–24.

Orlove, B. S. and Tosteson, J.: 1998, 'The Application of Seasonal to Interannual Climate Forecasts Based on El Niño-Southern Oscillation (ENSO) Events: Lessons from Australia, Brazil, Ethiopia, Peru, and Zimbabwe', *WP 99-3*, Institute of International Studies, University of California, Berkeley, 1999.

Parsons, T. R.: 1996, 'Taking Stock of Fisheries Management', *Fisheries Oceanography* **5**, 224–226.

Pauly, D. and Christensen, V.: 1995, 'Primary Production Required to Sustain Global Fisheries', *Nature* **374**, 255–257.

Pfaff, A., Broad, K., and Glantz, M. H.: 1999, 'Who Benefits from Climate Forecasts?', *Nature* **397**, 645–646.

Philander, S. G.: 1990, *El Niño, La Niña, and the Southern Oscillation*, Academic Press, New York, p. 293.

Philander, S. G.: 1998, Who is El Niño? *EOS Transactions* **79**, 13, 170.

Pielke, R. A. Jr. and Glantz, M. H.: 1995, 'Serving Science and Society: Lessons from Large-Scale Atmospheric Science Programs', *Bull. Amer. Meteorol. Soc.* **76**, 2445–2458.

Pulwarty, R. S. and Redmond, K. T.: 1997, 'Climate and Salmon Restoration in the Columbia River Basin: The Role and Usability of Seasonal Forecasts', *Bull. Amer. Meteorol. Soc.* **78**, 381–397.

Rayner, S., Houk, M. et al.: 1999, Institutional Issues in Adoption of Probabilistic Climate Variation Among U.S. Water Managers. Society for Applied Anthropology 1999 Annual Meeting: Constructing Common Ground: Human and Environmental Imperatives, April 21–25, Tucson, AZ.

Roncoli, C. (ed.): 2000, 'Anthropology and Climate Change: Challenges and Contributions', *Practicing Anthropology* **22** (4 - special issue).

Sarewitz, D., Pielke, R. A. Jr., and Byerly, R. Jr. (eds.): 2000, *Prediction: Science, Decision Making, and the Future of Nature*, Island Press, Washington, D.C.

Sharp, G. D. and Csirke, J.: 1983, *Proceedings of the Expert Consultation to Examine Changes in Abundance and Species Composition of Neritic Fish Resources*, Food and Agriculture Administration, San Jose, Costa Rica.

Sharp, G. D. and McLain, D. R.: 1993, 'Fisheries, El Niño-Southern Oscillation and Upper-Ocean Temperature Records: An Eastern Pacific Example', *Oceanography* **6**, 13–22.

Sarachik, E. S., Busalacchi, A. J. et al.: 1996, *Learning to Predict Climate Variations Associated with the El Niño and the Southern Oscillation: Accomplishments and Legacies of the TOGA Program*, National Academy Press, p. 171.

Siekevitz, P.: 1972, *The Social Responsibility of Scientists*, New York Academy of Science, p. 112.

Stern, P. C. and Easterling, W. E.: 1999, *Making Climate Forecasts Matter*, National Academy Press, p. 175.

Thorp, R. and Bertram, G.: 1978, *Peru 1890–1977: Growth and Policy in an Open Economy*, Columbia University Press, p. 475.

Trenberth, K. E.: 1997, 'The Definition of El Niño', *Bull. Amer. Meteorol. Soc.* **78**, 2771.

Villanueva Chang, J.: 1998, 'Chimbote es un mendigo con vista al mar', *El Comercio*, 7 Sep A8.

Walters, C. J.: 1989, 'Value of Short-Term Forecasts of Recruitment for Harvest Management', *Can. J. Fish. Aquat. Sci.* **46**, 1969–1976.

World Climate Research Programme: 1997, Climate Variability and Predictability: Initial Implementation Plan (DRAFT). International CLIVAR Project.

World Meteorological Organization: 1998, Commission for Basic Systems. Extraordinary Session (ITEM 4.3): Global data processing system-infrastructure needs for Seasonal to Interannual Climate Prediction. Karlsruhe.

Zapata Velasco, A. and Suiero, J. C.: 1998, *Naturaleza y Politica: El Gobierno y El Fenomeno Del Niño en el Peru 1997–1998*, Instituto de Estudios Peruanos, CooperAccion, p. 108.

Zapata Velasco, A. and Broad, K.: 2001, ‘Peru Case Study: Impacts and Responses to the 1997–1998 El Niño Event’, in Glanz, M. (ed.), *Once Burned, Twice Shy? Lessons Learned from the 1997–1998 El Niño*, United Nations University Press, Tokyo, p. 294.

(Received 22 January 2001; in revised form 14 December 2001)