2. THE PAST, PRESENT AND FUTURE CLIMATE RELATED TO FISHERIES

People have documented the coming and going of local fish resources for centuries. How much these changes were due to fishing or other causes has been a dilemma. The many issues of habitat protection, restoration, and utilization are beyond the scope of this document, but are definitely worthy of concern. As humanity has enjoyed the benefits of the recent two centuries or so of relatively amicable climate, ever more conflicts have risen as the Tragedy of the Commons evolves into fierce competition for access to limiting resources – particularly clean water and living space. The dilemma is how to cope with the uncertainty of future climate changes. Lessons from the past seem a good place to start.

Since systematic research into understanding fish reproduction success began, numerous fish species have been reared and studied to discover various keys to relatively better survival, diverse life history and growth patterns, and predation effects – in order to stabilize fisheries. Research into cause and effect in ocean productivity and fisheries production have been reviewed extensively elsewhere (c.f. Pearcy 1966; Smith 1978; Ursin 1982; Kawasaki 1983; Bakun 1996; Caddy and Bakun 1994; Longhurst *et al*. 1995; Polovina, Mitchum and Evans 1995; Schulein, Boyd and Underhill 1995; McFarlane, King and Beamish 2000; Harrison and Parsons 2000). With the collapse of the California sardine, in the 1940–50 period, and then the Peruvian anchoveta in the early 1970s, fisheries research was intensified in the eastern boundary currents (see historical reviews in Scheiber 1990; Crawford *et al*. 1991; Sharp 2000). Throughout this century, lessons from each study were carried from region to region, and then applied to more offshore species, by analogy, as fleets grew, and spread out onto the high seas (c.f. Schwartzlose *et al*. 1999, Harrison and Parsons 2000). The collapse of cod and other major fisheries in the northwest Atlantic in the late 1980s caused a complete shift in emphasis, as the public finally began to grasp that it takes more than only good science to manage living resources (Finlayson 1994, Dobbs 2000; Glavin 2000).

Coastal pelagic fishes of the world, particularly those off California, are amongst the best-studied populations in the world (reviewed in Sharp 1998, 2000). Following leads from early studies by Lasker (1978), and colleagues around the world, Cury and Roy (1989) evolved the theory of "Optimal Environmental Windows" for fish survival. Climate and weather-related drivers of the alternative states within the eastern boundary current regions are reasonably well understood. These forces, along with decadal scale and longer fisheries sequences are now tied together in many studies of Climate Regime Shifts and their fisheries implications. The story simplifies to taking measures of wind speed and direction, and other measures, and comparing the results to upper ocean temperatures, primary production, and various fish species' annual recruitment records (Figure 7).

2.1 Ecosystem responses to various scale climate forcing

Twentieth Century fisheries scientists have provided abundant examples and documentation to show that fisheries dynamics involves much more than only isolated fish stocks and fishing mortality (see for example reviews by: Hjort 1914, 1926; Roger Revelle 1947 (in note to John Isaacs, quoted in Scheiber 1990); Bakun *et al*. 1982; Bakun 1996; Sharp and Csirke 1983; Csirke and Sharp 1983; Glantz 1992; Sharp 1997, 2000; Boehlert and Schumacher 1997 – amongst many others). Their common thesis is that the oceans, hence fisheries are connected to larger scale dynamic forces and processes.

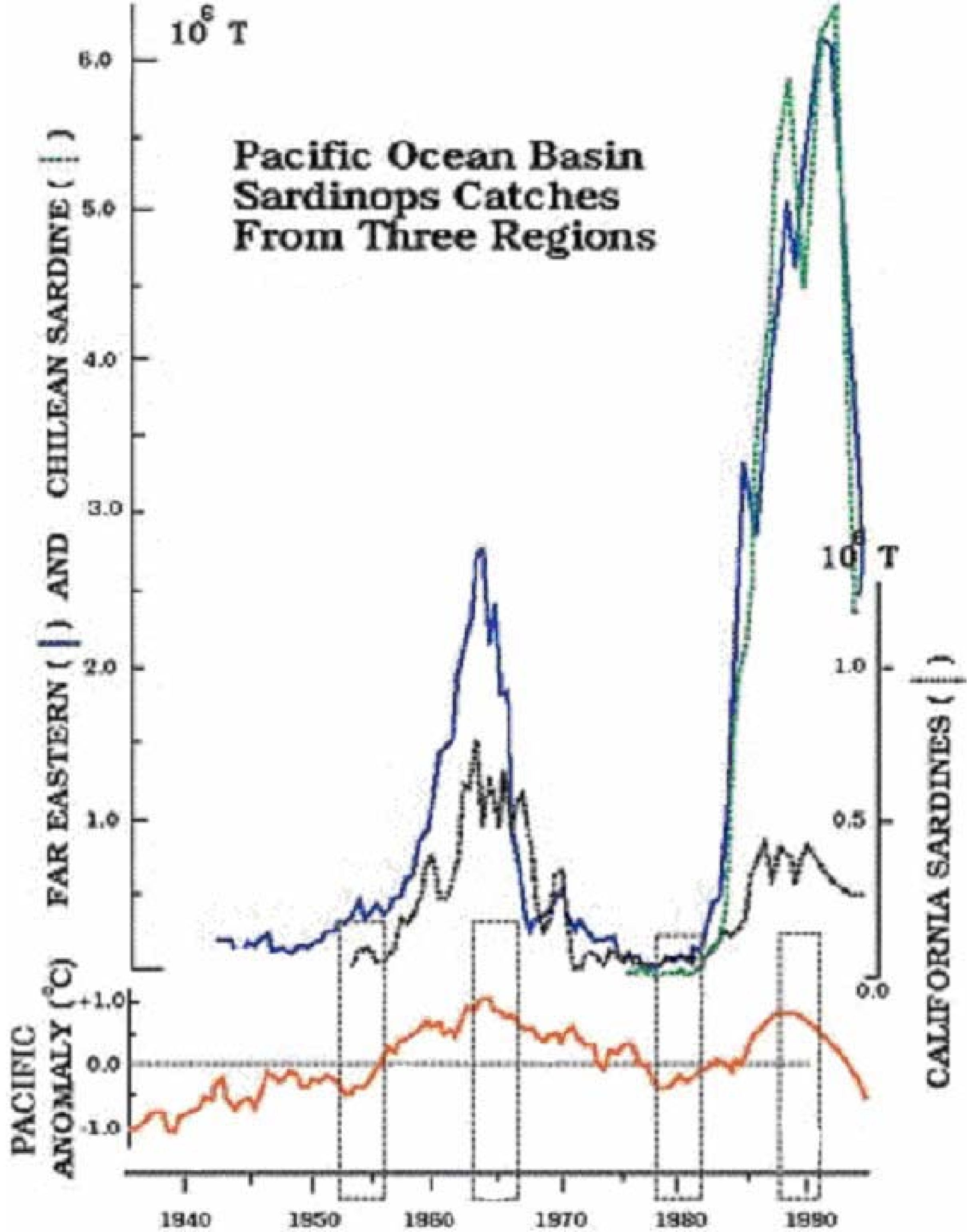

Figure 7 Is an update of the now famous Pacific Sardine Trilogy from Kawasaki *et al.* (1991) in which plots of ocean temperature changes off coastal Japan show the insightful relation of population blooms to upward sea surface temperature (SST) trends – as a starting place. Declines appear to be related to ocean cooling (along shore wind-driven upwelling periods – see Figure 4 – and related explanations).

Figures 8 and 9 show that many forces and processes interact, and ultimately reach downward to the all-important local scale where the critical life-history processes of fishes – and other species – take place (Sharp 1981a, 1988).

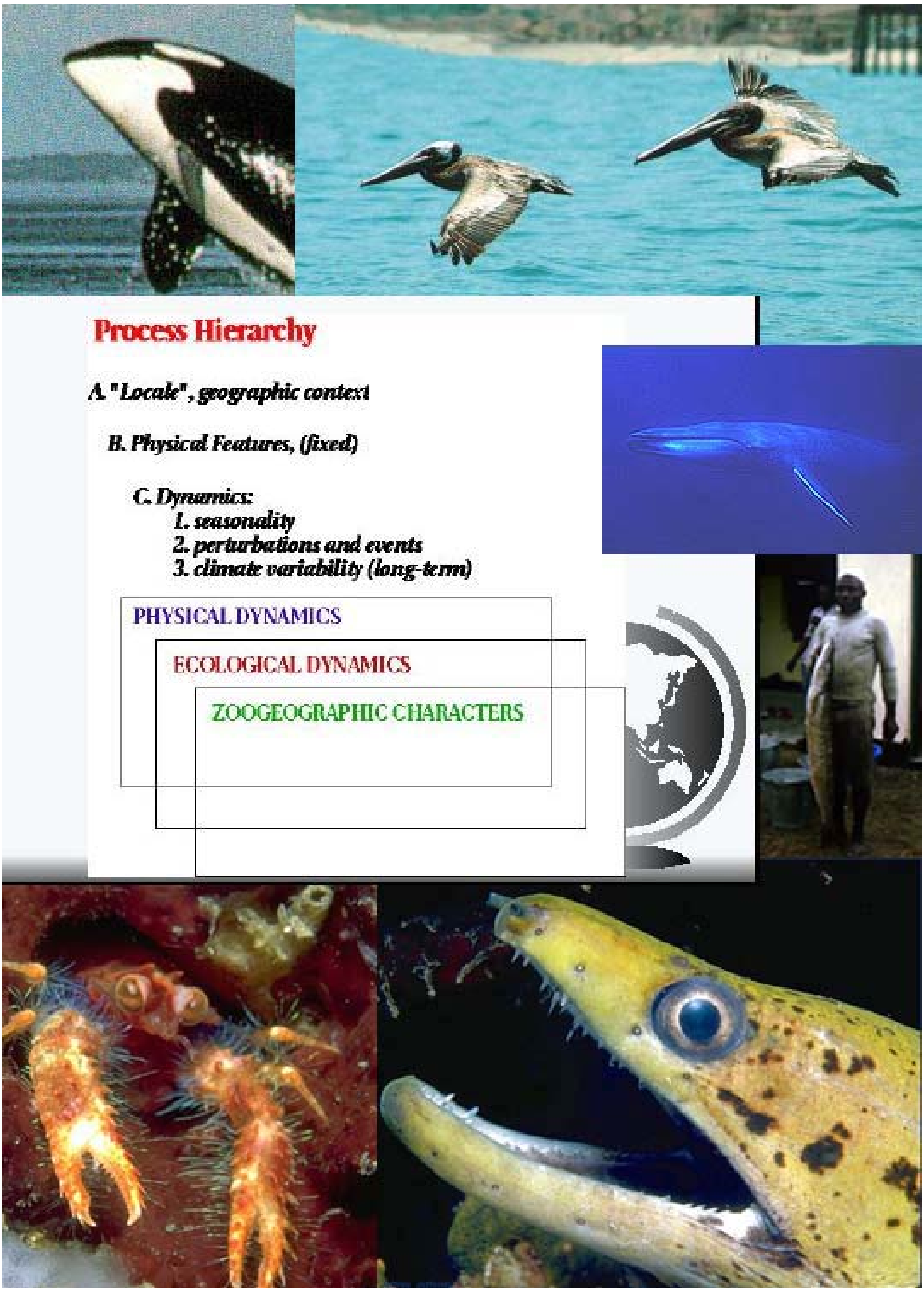

Figure 8 The Process Hierarchy (Sharp 1988, 1997) extends outward from each local living resource's (or researcher's) perspective: The objective is to understand the patterns of change in each of the three coloured strata, and how they result in the spatio-temporal dynamic zoogeography that we depend upon for sustenance.

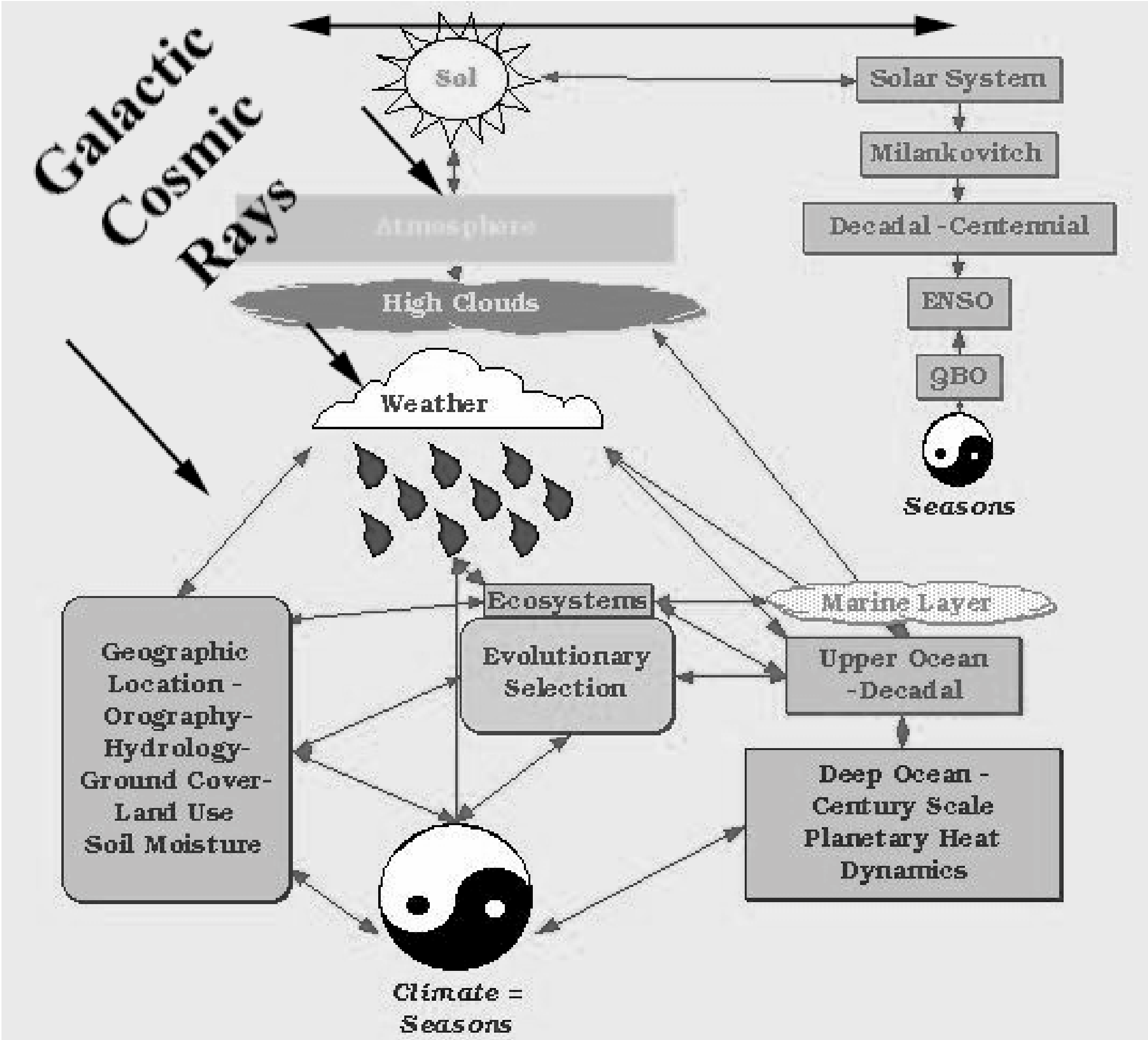

Figure 9 Connected icons show some conventional sun/climate/ecological interactions. These are shorthand for very complex, non-linear processes that are many cases difficult to measure and model. They each operate on very different time and space scales. (Note that all these processes take place within a steady hail of Galactic Cosmic Rays (c.f. Ed Mercurio's URL for website review), arriving from all directions, and myriad sources beyond our influence, or general knowledge, providing forcing for poorly understood processes).

The fisheries questions have converged on somewhat direct local and regional measures of an array of factors, from wind speed, upwelling and downwelling rates, primary production, and species interactions. This has evolved into Fisheries Physiological Ecology, hopefully now maturing into Systems Ecology. For example, ocean primary productivity is a measure of growth and reproduction of algae and other plants. The resulting growth is a complex consequence of available nutrients, light, and temperatures, as well as predation rates and parasite loads. The oceans, and therefore their all-important plants, also respond to local weather such as wind speed, cloud cover, and incident sunlight. Primary production is only the first of several stages in transformation of nutrients and carbon dioxide into living cell building blocks Meanwhile there are ongoing debates over how to truly measure and quantify primary production (c.f. Welchmeyer *et al*. 1999). It is difficult to start from conventional Light/Dark bottle measures and deduce potential fisheries production. In all aquatic ecosystems, primary production is seasonal, as the winds, light levels, and needed nutrients vary over time, with the weather/climate. So here the initial connections to biological variability are found.

The predator-prey network, known as the food web, takes over after these initial light-driven chemical transformations, and relays the energy and materials throughout the Trophic Pyramid, and on into the broader Ecosystem. Systematic variations, i.e. annual seasonal, ENSO-related and longer, involve processes that are usually found to be analogous to the Warm/Cool ocean fish faunal dominance shifts that result in the 50–70 year start-to-end phenomena that are now recognized as two 25–35 year “Climate Regimes” within the basic cycle. These issues are reasonably well described in several early and recent compendia of research and monitoring requirements for ecosystem-based fisheries management (Caddy and Sharp 1986; Gomes, Haedrich and Villagarcia 1995; Boehlert and Schumacher 1997).

Many have asked “Why has fisheries management been so ineffective?”

Within the contexts that most ocean fisheries operate, the causalities for many of the observed phenomena have been quite elusive. It seems that every year we learn about more influences from beyond any locally measured fishery, or ecosystem, that can affect resource status and thus fisheries productivity. We have also learned that, primarily, the essential system-wide information collection has been resisted due to “cultural differences” between agency-based stock assessment staff, fisheries scientists, and fisheries oceanographers. Stock assessment has evolved into an accounting art form that employs generic mathematical logic structures and an array of simplifying assumptions to create “model” populations whose major interactions are defined as post-recruitment fishing mortality. Most every other source of variability is “assumed away”, or combined within a “well recognized” constant (i.e. q, the catchability coefficient – c.f. Sharp, Csirke and Garcia 1983) – and ignored. The other two applied fisheries sciences’ methodologies adopt mostly simplifying assumptions that are appropriate to dynamic ecosystems and subsequent fisheries interactions.

Does that mean that everything in the oceans needs to measured – everything that effects every component of marine ecosystems? Not really. It does, however, strongly suggests that more integrated approaches amongst the geosciences, fisheries science, and fisheries management need to be encouraged.

Many fisheries scientists and managers would find fisheries forecasts to be very useful. They would also value any proxy information that offered reasonable lead-time, and yield insights into when, for example, changes might occur in the warm-low upwelling – or the contrasting cooler, wind-driven upwelling periods. Time and space scales of the phenomena needing monitored by climate and ocean researchers provide the major dilemmas. It is not only the local fisheries variations that cause problems, but the ever-expanding time and space scales of the various forces that shape these local phenomena. The questions and their respective answers become particularly complex when dealing with ocean ecosystems.

2.2 Climate patterns vs weather patterns

Likewise, the distinction between weather and climate needs to be made clear, reflecting the various media involved. While daily weather patterns are most dynamic, within their seasonal and local contexts, ocean weather has its own time and space scales. These ranging from near instantaneous responses to changes in surface winds and light levels, to lagged responses associated with the hierarchic transfers of forcing processes, into the depths, and outward from the stimulus force in the form of waves, at the surface and otherwhere.

The relative stability of essential habitat and other essential conditions for locale-specific fish population survival have been described elsewhere (c.f. Sharp 1988, and the Aquatic Ecosystems series within Elsevier's Ecosystems of the World, David Goodall, editor in Chief). Surface Winds, Currents, Tides create the physical movements associated with diurnal, monthly, and seasonal weather that affects ocean processes. Sunlight is fundamental to the biological productivity, and is modulated by clouds, seasons, and general circulation dynamics forced by the surface winds, currents and tides. Bakun and Parrish (1980) made the first comparative study of eastern boundary current upwelling systems, focused on seasonal surface wind field forcing. Hunter and Sharp (1983) provided the insight into comparative global and regional consequences of tidal forcing. While others have focused on specific regional patterns of responses, Caddy and Bakun (1994) surveyed global production processes related to fisheries. Seasonal currents are best evidenced in monsoon related studies, such as those described by Thompson and Tirmizi (1995) and Pauly and Matsubroto (1996) while the entire ocean reflects the complexities of seasonal and longer term wind field changes that along with the earth's rotation and tidal forces that produce the complex seasonal to climate-scale ocean current dynamics, and diverse ecological responses.

Events vs Weather vs Climate – define the dilemma of those studying and hoping to forecast ocean fisheries production. Nowhere in Nature is this dilemma more obvious. When the oceans' constant motions are enhanced or perturbed by "unique" events, such as the closure of the Panama Isthmus, or a Tsunami (unleashed by a strong seismic event) – currents and tides are subjugated to novel forces, depending upon the longevity of the changes and forces. In the first case, somewhat permanent changes are forced, both locally, and basin wide. In the other, once the Tsunami's energies have been dissipated, only minor oceanic ecological influences are likely, despite any permanent changes that occur nearshore or upland. On short time scales, locales can be altered in dramatic fashions, and become important to ecological processes within entirely different contexts.

Weather, on the other hand, is the "normal" expected pattern of change shaped by both seasonal forces and remaining footprints from previous forces, embedded in the ocean's fluid dynamics. These "footprints" are the first vestiges of climate processes, and can be observed as measurable deviations from the "normal" expectations for each site, and time period. Therefore, the annual seasonal cycle is considered to be the limit of weather, per se. Anything that substantially perturbs this pattern is termed a Climate Change, or maybe just an "Event". El Niño – Southern Oscillation Events are the most frequent of these "expected" climate perturbation processes. These phenomena have been most identifiable in their tropical contexts (c.f. Allan, Lindesay and Parker 1996), but recently, with more sophisticated space-based observing tools their influences can be tracked from their source into the polar oceans (c.f. White, Chen and Peterson 1998, Wyllie-Echevarria and Wooster 1998). Varying in frequency and intensity, over time, ENSO Events often create the dilemma of defining real Climate Changes. Certainly there is a lot more to be learnt about the various larger scale forces, so that their sequential effects are better understood.

2.3 Historic climatic changes and social and fisheries responses

From the results of paleoclimatic, paleosediment and climate studies, it deals with global patterns of climate change and marine ecological responses. For example, studies of undisturbed anoxic sediments from the Santa Barbara Basin, off Los Angeles, provided a dynamic changing abundance sequence for sardine, anchovy, and other fishes for nearly two millennia (c.f. Soutar and Isaacs 1974, Baumgartner *et al*. 1989, Sharp 1992). Clearly, humanity is dependent upon many uncontrolled, yet patterned processes. The race to discover climate indices that provide forecast capabilities for known phenomena has escalated.

The key to understanding and relating the relationships between these extended time scale observations and the shorter record sets used by Global Warming buffs, is to compare the relative variability of the shorter and longer sequences, on a standard scale. Because the majority of instrumental measurement records extend from 1950 or more recently to the present, it is easy to, do analyses, and make graphics to present trends that too often turn out to be out of context, or misleading. One of the more important points that is made is the fact that the recent 50-year period of extensive climate records is notable for its lack of dynamics, and low variance in comparison to century or longer time-scale records.

Climate is the long-term average expected seasonal pattern, while weather is the more variable seasonal phenomena that are observed. The most powerful, identifiable sequence of ocean-atmosphere interaction-driven events that perturb expected seasonal Climate Patterns are ENSO Warm and Cold Events, respectively known as El Niño and La Niña. But even the intensity and frequency of ENSO Warm Events vary in time, on decadal and longer time scales as documented in Figure 10. So, the need to recognize, as well, that climate – and related ocean productivity (c.f. Hubbs 1960; Laevastu and Favorite 1980; Nixon 1982, 1988, 1997; Ebbesmeyer *et al*. 1991; Murawski 1993; Polovina, Mitchum and Evans 1995; McGowan, Cayan and Dorman 1998; Reid, Planque and Edwards 1998; Reid *et al*. 1998; Hollowed and Wooster 1992, 1995) – varies on several time and space scales – but discounted as being an unaffordable requirement by Hilborn and Walters (1992), to which I respond "If it is not monitored and accounted for, what value are the estimates and analyses without it?" However, climate indices and fisheries Bloom and Bust cycles appear to vary in similar patterns (Figure 11). The real issue is whether, once again, there is a direct causal link, or these are merely correlated consequences of larger scale processes. The answers lie in monitoring linked processes and collation of observations on all time and space scales.

From studies of Earth climate history, from weather observations made routinely since 1854, it can be seen that the Earth's last half of the twentieth century's seasonal dynamics were really not very great, relatively speaking. These are records from the Comprehensive Ocean and Atmosphere Data Set, or COADS, which have been compiled for climate research. One important lesson from the COADS observations, as is that the strongest climatic signals are found in the winter month patterns, rather than other seasons – or annual means. The Winter-Only patterns are therefore a good place to start looking for right questions about climate variation. Figures 12a, b, and c, show the Winter Surface Wind departures from the long-term mean since 1854. Note that although the scales vary by latitudinal band, and ocean basin, the patterns are quite similar, with short regional leads or lags. Also note the monotonous slow upward trend of the recent 50 years, in contrast to the previous century.

Everyone should be aware that the last deep Ice Age ended only 18 000 years ago, and that most of the Earth, at latitudes higher than about 45ºN and about 50ºS were under or affected by glacial ice. Every species, fish, mammal or birds, that can be found today at these and higher latitudes have "recolonized" during the ensuing warming period. These same populations have also more often than most people recognize, been pushed back and forth in response to decadal to century-scale climate changes by repeated glaciation/deglaciation.

Without recounting all of human history, humans actively responded to these changes through migrations, and myriad colonizations, and recolonizations.

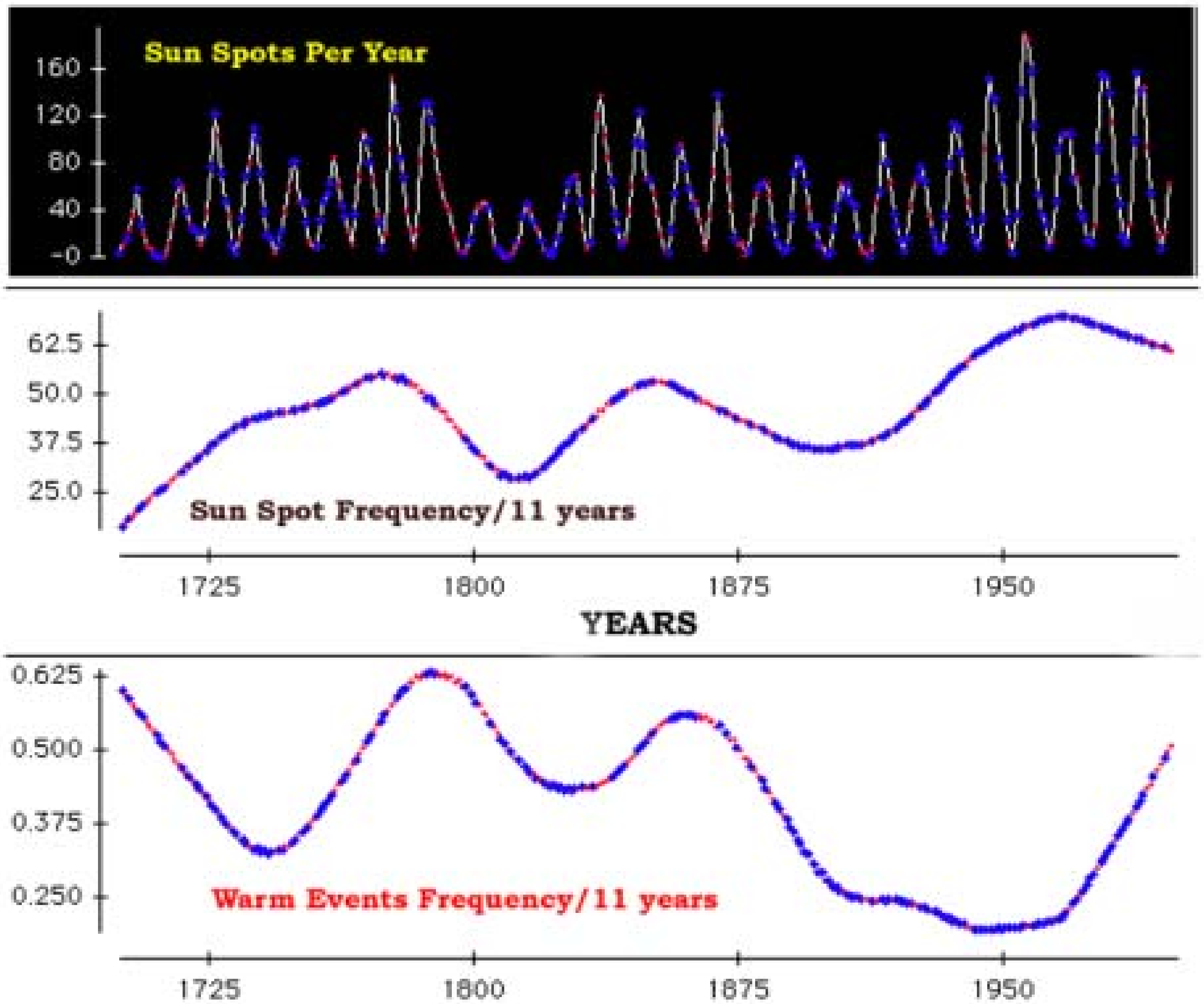

Figure 10 Shows the time series of ENSO Warm Event Frequency from Quinn (1992) plotted against sunspot numbers (top), and sunspot frequency for averaged 11 year records. Quinn employed the Nile River gauge data, ships logs, and assorted local records from various missions, outposts and family steads to create the time series. Note that the frequency records were the lowest from about 1890 until about 1975, suggesting that Average Global Temperatures have little to do with ENSO Warm Events.

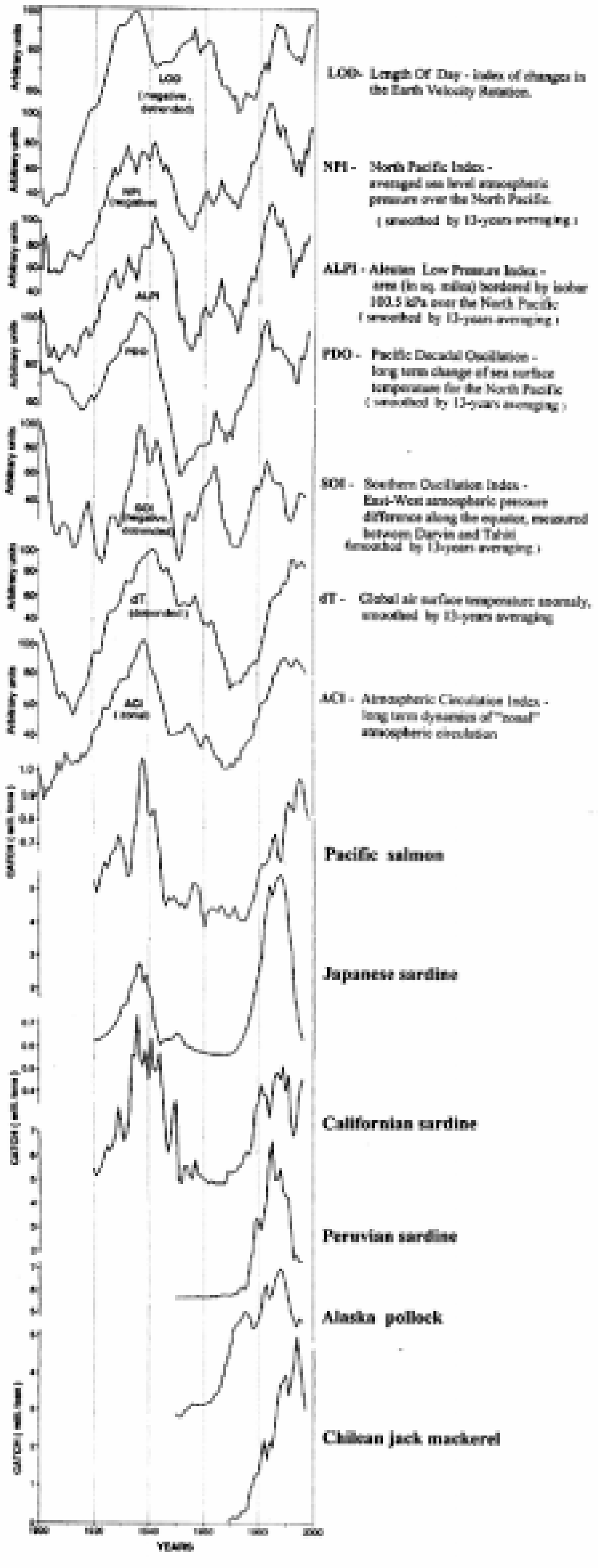

Figure 11 Provides a comparison of several of the available climate indices, including the rise and fall of a characteristic group of the Warmer ocean associated major fisheries catches. Correlates – or causes?

Hunting and gathering dwindled as they were replaced by integration of farming, herding and ranching, done outside the walls of larger population centres. People thrived under stable warm wet periods. As a result, at the end of the Medieval Warm period (twelfth century) it has been estimated that there were about 300 million humans.

Despite enormous losses of life and displacements due to plague, smallpox, and other diseases transported about the world by travelers, or into homes by vermin during the cooler era that intervened, by the early Nineteenth Century the human population had attained about one billion. It has taken less than two hundred years since then to reach six billion. Meanwhile, on the oceans, fishing activities expanded. Navigation tools and many other technologies were developed, allowing fleets and new methods to spread unrestrained, until fleet growth and landings from the sea finally began to slow down in the mid 1980s, and eventually, decline – as fished populations responded, and quantities and qualities of products shifted (c.f. Pauly *et al*. 1998).

Aquaculture also expanded more or less continuously with human population growth, since early Chinese efforts and local projects (Sharp 2001). Most of the fish culture activity was "put-and-take" in the sense that the organisms, e.g. carp, *Tilapia*, oysters, etc., were most usually only relocated. They were expected to "feed themselves" by eating the algae production and other nutrients from pond systems. Heavily utilized habitats, e.g. rice paddies or ponds, were fertilized using human and animal wastes. However, as many regional fisheries leveled off – or failed, the "enhancement" of natural fish populations became a focus.

Atlantic Ocean Wind Speed Departures

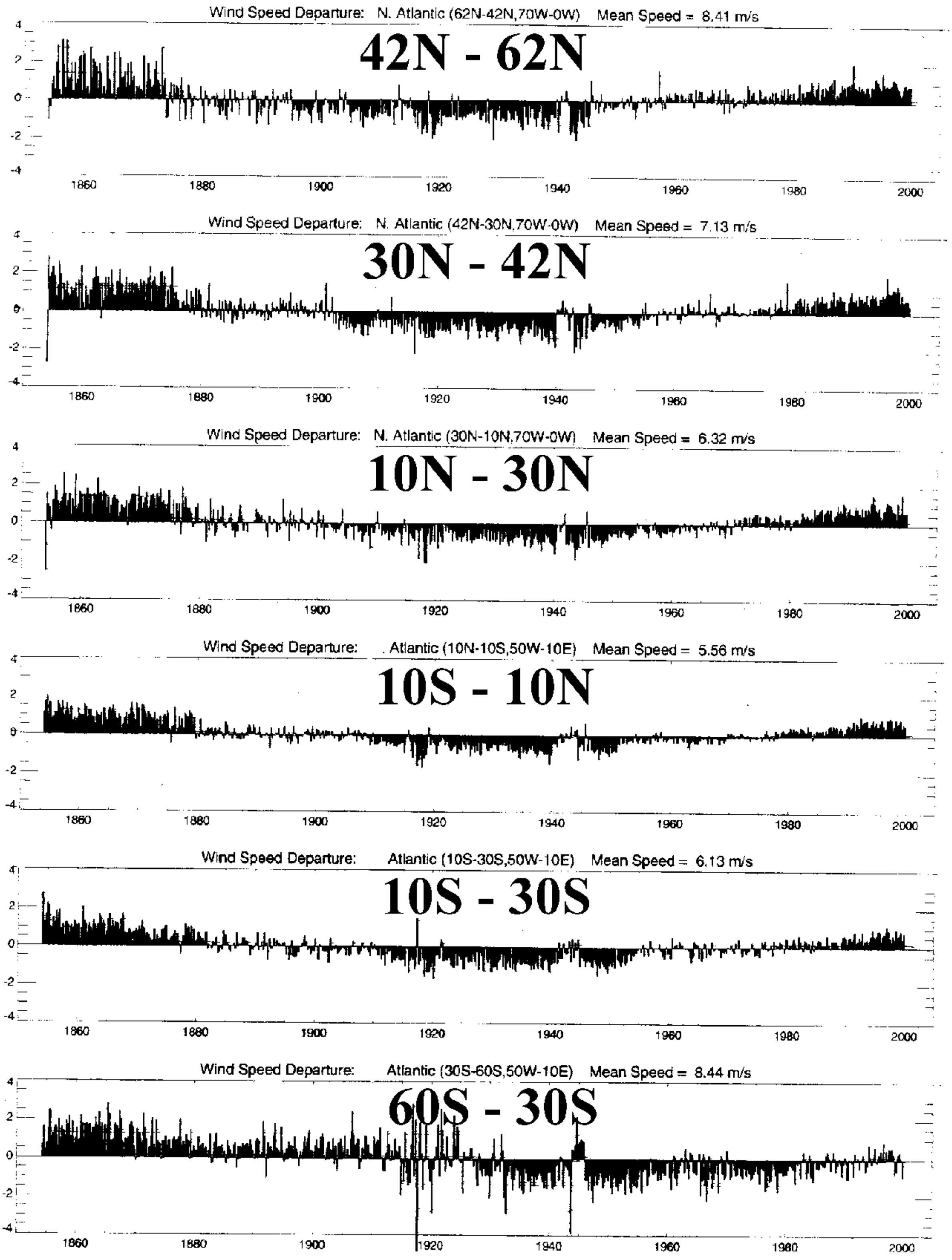

Figure 12 a

Pacific Ocean Wind Speed Departures

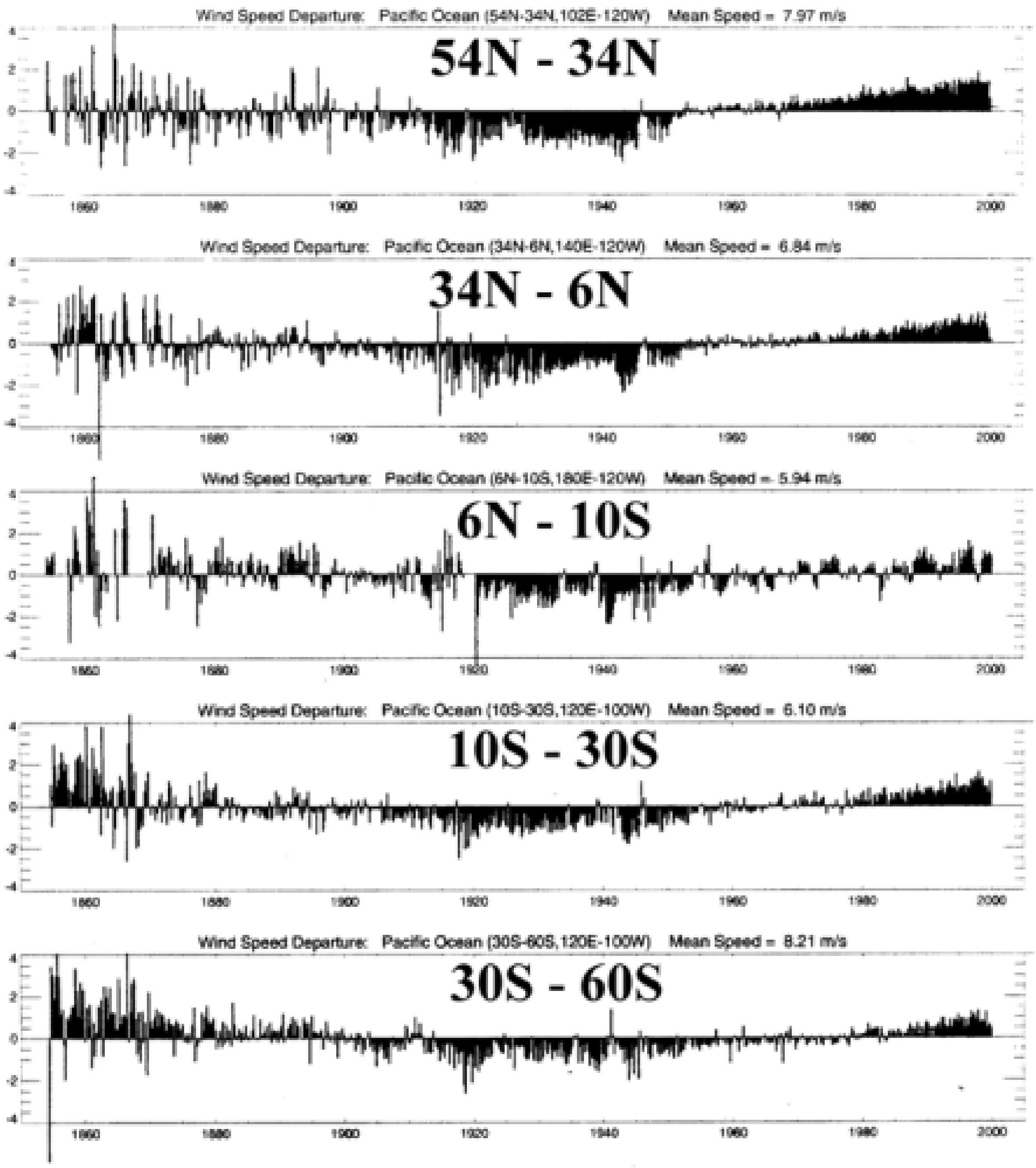

Figure 12 b

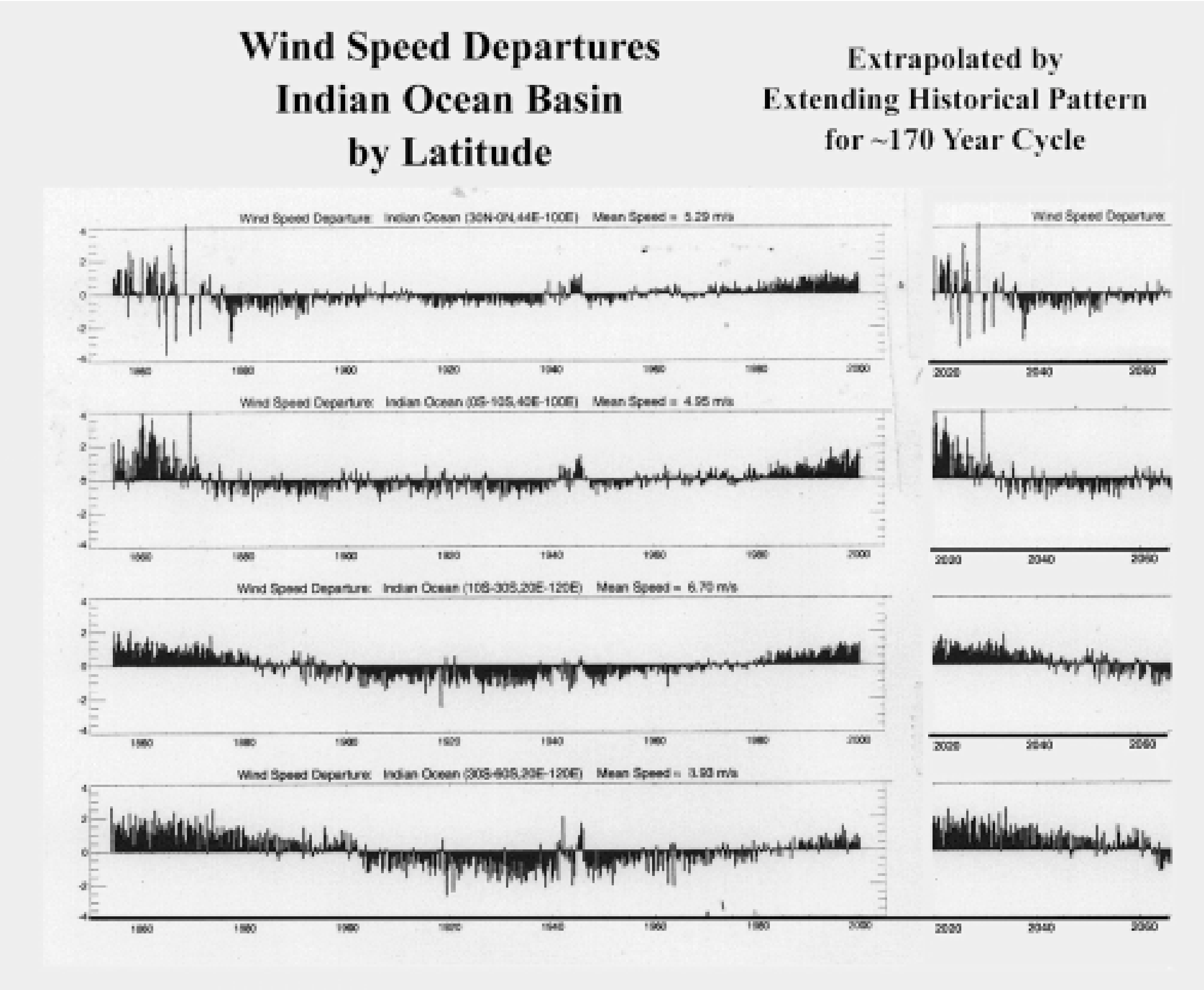

Figure 12 c

Figure 12 Are time series of average Wind Speed Departures from the mean wind speeds, (given for each sector) since 1854 for latitudinal sections of the three ocean basins, (a) The Atlantic; (b) The Pacific; and (c) the Indian Ocean. Note the similarity of the trends for each record and all the regions. The Indian Ocean records (c) has had the early part of the records "added" onto the right side of the graphic, to show the likely pattern of these wind records, if they do indeed follow the 170–180 year repetitive pattern as suggested by paleological records that measure solar activities. These are used by Dr Fletcher to help construct a Climate Futurecast for the twenty-first century.

The first seafarers were likely the folks who colonized Australia from Southeast Asia, some 40 000 years ago, about the same time that the last Glaciation began. There have been many pulses in and out of Africa, due to extended drought, and then recovery. The development and rise of seafaring under the influence of the seasonal monsoon around North Africa and the Indian Ocean was a major contribution to the cultures that evolved along these shores. People that colonized inland areas or coastlines where more erratic climate influences dominated tended to be migrant. They were also more likely dependent upon hunting and gathering, with some local fishing activities. There were also several well-documented subsequent climate changes that supported the aggregations of agricultural communities, and the development of specialty trades, and barter economies. Recurrent drought was their nemesis. These peoples' primary assets were the evolving technologies that made agriculture more efficient.

Various fisheries had undergone collapses, and the fishermen either learned to fish for other species, moved into other areas where they would look for similar resources, or took up other means of making a living. This included crewing exploratory vessels, industrial whaling ships, or eventually, trading ships. The mid nineteenth century collapse of the Arcto-Norwegian cod resource stimulated G.O. Sars to develop the concept of rearing early life history stages, to protect them against natural predation and starvation, and thus enhance their survival to stages and ages at which they were less vulnerable, and more able to fend for themselves. He developed artificial propagation of marine fish fry in Norway. Sars fertilized, hatched and released 67 million cod yolk-sac fry. G.O. Sars is credited for starting modern fish hatcheries for restocking declining fish resources – and modern fisheries science as well. This approach has thrived since the 1850s until today.

The next era began in 1872 as North America's history of fish hatcheries began when the American Fish Culturists Association Appropriated $17 000 for the Government to begin fish culture development. Also in 1872 Livingston Stone made the first salmon egg collection for artificial fertilization, at Baird Station on the McCloud River. On 10 October 1872 he shipped the first 30 000 chinook salmon eggs via rail, of which 700 survived to fingerling size.

Back in Norway, in 1882 Capt. Gunder Dannevig founded the Flødevigen hatchery at Arendal, Norway, beginning a century-long cod enhancement program that was finally closed in the 1980s, only because the hatchery staff had never really bothered to prove that the released codlings were caught in local fishery. Also in 1882 – Adolf Nielson, a Norwegian fish hatchery employee visited Newfoundland, on request, and helped create an initiative to build a fish hatchery at Dildo Island, to refurnish the failing cod recruitment off Newfoundland. The project was halted in the late 1880s, as the cod had recovered on their own, thus providing early insights into Nature's patterns. Apparently there was a sequential failure of Atlantic cod, that spread from east to west, as environmental conditions shifted in time and space. Their recovery occurred in similarly lagged temporal and spatial contexts. During these "collapse periods" other species thrived, some from absence of predation by cod, and others due to the distinctly different ambient patterns.

In 1981, the Norway's Svanøy Foundation sponsored a workshop on cod culture to review the history and ongoing activities in Norway. Of particular interest was the concept of raising codlings in nets underneath their burgeoning industrial salmon culture pens, to take advantage of the uneaten feed that passed through the pens as a result of the satiation-feeding approach that was used. This resulted in a cod culture effort that was sometimes quite successful. Other times, and places, it failed. Workshop attendees encouraged Norwegian fish farmers to include cultured cod juvenile-tag-and-recapture studies. The eventual results of the tag/recapture studies that ensued were more than encouraging, as within the first few years, up to 20 percent of the tagged cultured fish were returned from the local fishery, proving, finally, the worth of cod culture. Of course, there were years when entire stocks of the young codlings were wiped out by blooms of various invertebrate predators in the grow-out ponds before they were released, and other years when they were likely eaten by abundances of predators within the fjord system before they got to sea.

The major message that stimulated most of the ensuing stock-enhancement activity is that there are no guarantees from Nature about year to year recruitment successes (c.f. Smith 1978; Csirke 1980; Sharp 1981a,b; Bakun *et al*. 1982; Kawai and Isibasi 1983), nor decade to decade population stability (Kondo 1980; Csirke and Sharp 1983; Sinclair 1988; Ware 1995; Ware and McFarlane 1989; Ware and Thompson 1991). Thus the generic failure of most conventional stock forecast models based on "mean" expectations (Sharp, Csirke and Garcia 1983; Koslow, Thompson and Silvert 1987; Koslow 1992). The obvious answer to the individual species dynamics is best expressed through the various unique population responses of the major fisheries stocks identified by Klyashtorin (1998, 2001) for which Catch Statistics exist for nearly a complete century, or about the minimal reference time to relate climatic causes and effects (see Figure 13, below).

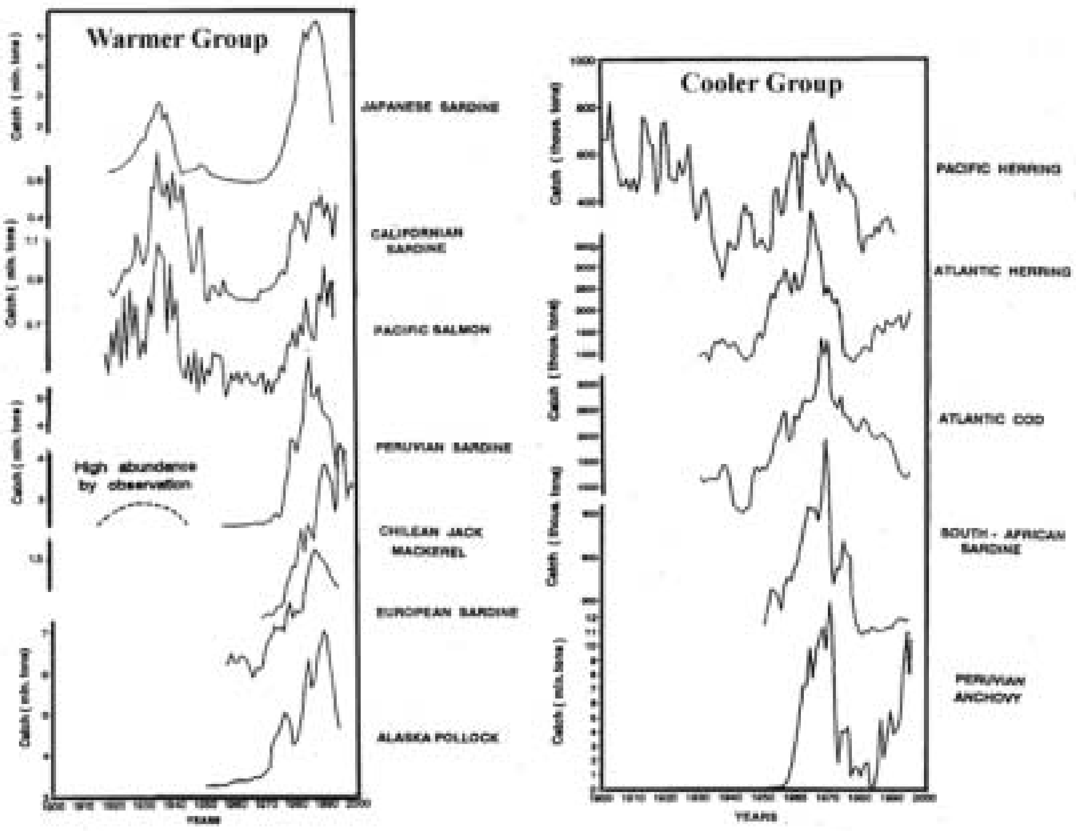

Figure 13 Provides species by species commercial catch histories for 12 of the world's most productive fisheries (Klyashtorin 2001). Each region has a major fishery production from each period when warmer corresponds to more zonal (east-west) winds, and the cooler period are dominated by meridional (north-south) winds. The latter tend to induce coastal upwelling, and nearshore production, while the warm periods depend upon other modes of nutrification and ecological production. Both are reflected in patterns of specific ACI and -LOD changes.

For most productive regions, there are two quite responsive populations, each of which thrives on opposite extremes of the normal climate variations within the ~55–70 year dipolar periods. A third, less responsive, usually much more numerous species group simply wobbles along throughout this variation, some never blooming, others like the *Sebastes* species, having spikes in larval survival and rercruitment successes that carry them for periods longer than 50 to 100 years (Norton and Mason, in press).