HISTORICAL REVIEW

The development of recruitment fisheries oceanography in the United States

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ABSTRACT

Recruitment fisheries oceanography studies the impact of the environment on the annual production of young to fished populations (finfish as well as invertebrates). Interannual variation in recruitment is the most important source of biological variability facing fisheries managers. Because most variation in recruitment occurs during early, mainly planktonic stages, recruitment fisheries oceanography usually integrates studies of plankton and physical oceanography. The concepts upon which these studies rest were first expressed in the late 1800s by Spencer Fullerton Baird, the first Commissioner of the US Commission of Fish and Fisheries. These concepts appear to have been independently developed by Johan Hjort and others in northern Europe in the early 1900s, and brought back to the United States through contacts between Hjort and Henry Bryant Bigelow, who passed the ideas to his students at Harvard University, including Lionel Albert Walford and Oscar Elton Sette. Although both Walford and Sette did their initial work in recruitment fisheries oceanography off the US east coast, as federal fisheries scientists, they were sent to California in response to the decline of the sardine fishery, where they incorporated the ideas of Hjort into the programme that has become the California Cooperative Oceanic Fisheries Investigations (CalCOFI). The original plan for CalCOFI research was to provide a test of Hjort's ideas. Scientists working with CalCOFI implemented this plan and conducted subsequent research that had its roots in the ideas expressed by Baird. This research was in marked contrast to the fishery-yield orientation of most fisheries research that was being conducted at the time on the west coast of North America, under the dominating influence of William Francis Thompson. In recent years, federal fisheries programmes have investigated recruitment processes of a number of other fish stocks, and considerable effort has been expended toward refining the conceptual framework beyond the hypotheses of Hjort. This paper expands on this history, making note of scientists who were particularly important in the evolution of this discipline. We conclude that although recruitment fisheries oceanography has become a well-established field of study, and many technological advances have been made, the recruitment process is still not well understood and fluctuations in year-class abundance remain a major source of uncertainty in managing marine fisheries.

Key words history, ICES, CalCOFI, Baird, Hjort, Sette, Walford

ORIGINS OF THE UNITED STATES FISHERIES AGENCY[1]

Although Thomas Jefferson, as Secretary of State in George Washington's cabinet, presented the first report to the Congress on the status of US fisheries in 1791 (Jefferson, 1791), it was not until 1871 that the US Commission of Fish and Fisheries was established by Congress (Cart, 1968). One of the reasons leading to the establishment of the Federal Fish Commission was concern over the declining catches of fish off the coast of New England (Smith, 1994). Spencer Fullerton Baird (Fig. 1) was appointed as the first Fish Commissioner and served for 16 years, until his death in 1887. Baird was a naturalist and the Curator of the Natural History Museum at the Smithsonian Institution in Washington, DC. On his own, he had already been investigating the decline in fisheries off New England for several years during summer visits to the Woods Hole, Massachusetts area. Baird emphasized the importance of understanding life histories of fish in managing fisheries. Baird, with lobbying by the newly formed American Fish Culture Society (later to

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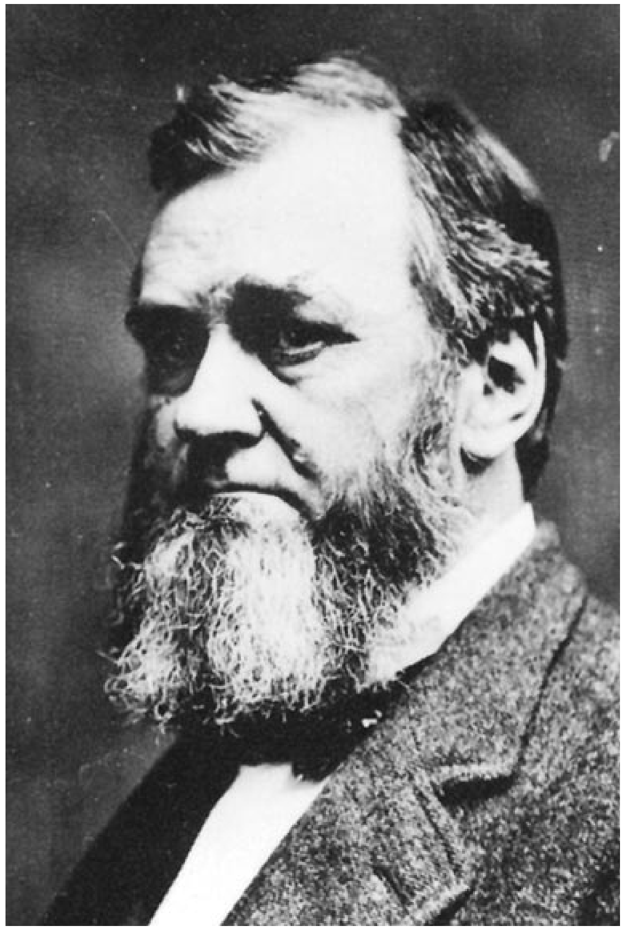
Figure 1. Photograph of Spencer Fullerton Baird. Used with permission of National Marine Fisheries Service.



Spencer Fullerton Baird
(1823–1887)

Birthplace: Reading, Pennsylvania
Education: Dickinson College, 1836
Experience:

1850–78	Assistant Secretary of the Smithsonian Institution, where he established the Department of Invertebrates in 1856. In the same year, he also established the division of fishes of the US National Museum. The first fish catalogued in the Smithsonian's research collection of fishes was a sucker, *Catostomus hudsonius*, which Baird caught in Lake George, New York. Many of the fish in the early collection were Baird's private specimens (Schultz, 1961).
1851–85	First Permanent Secretary of the American Association for the Advancement of Science (AAAS).
1878–88	Secretary of the Smithsonian Institution: responsible for the development of the Natural History Museum.
1871–87	First Commissioner of the independent US Fish and Fisheries Commission.

Spencer Fullerton Baird was a seminal figure in the development of natural science in the United States, and his professional life has been well documented (Allard, 1978). Baird is also considered to be the father of fisheries science in the United States. His original programme for fisheries research contemplated oceanographic and meteorological investigations, biology, ecology, parasitology, and even population dynamics (McHugh, 1970). Baird's concept of the role of the federal government in maintaining and preserving the fishery resources of the country stressed biological and oceanographical research, artificial propagation, and the compilation and use of fisheries statistics (Cart, 1968). Between fishing disputes and the tremendous scientific potential of oceanography, Baird saw an opportunity to apply science to the solution of practical problems. He also recognized that an understanding of fishery declines could be obtained only through large-scale investigations encompassing many fields of science (Allard, 1988). However, development of fisheries science in the United States was inhibited by Baird and his immediate successors in the Fish Commission, who placed great importance on hatchery culture as a solution to the problems of marine and freshwater fisheries. As a consequence, the Fish Commission embarked on a vigorous, and apparently completely futile, programme of fish culture which persisted for more than 60 years (McHugh, 1970).

Some quotes from Baird illustrate his views of fisheries research, and clearly anticipate the need for recruitment fisheries oceanographic studies:

> "The profitable study of useful sea fishes can not be prosecuted without a knowledge of their food, the food of their food, their respective friends and foes, the habitat of the several species, and their means of passing from one region to another in the embryonic as well as in the adult stage. The temperature, currents, and specific gravity, also, should be studied in connection with the migrations and habits of pelagic forms" (Baird, 1880, quoted in Fish, 1926).
>
> "We must ascertain…at what time the fish reach our coast, and during what periods they remain; when they spawn and where; what is the nature of their food; what localities they prefer; what agencies interfere with the spawn of the young fish; what length of time elapses before the young themselves are capable of reproducing; for how many years the function of reproduction can be exercised; and many other points of equal importance" (Baird, 1872).
>
> "Work out the problems connected with the physical character of the seas adjacent to the fishing localities, and the natural history of the inhabitants of the water" (Baird, 1872).
>
> "Research into the general history of the waters was considered legitimate, as, without thorough knowledge of the subject, it would be impossible to determine, with precision, the causes affecting the abundance of animal life in the sea" (Baird, 1872).

become the American Fisheries Society), was soon able to parlay the Fish Commission's initial appropriation of $5 000 first into $15 000, then in 1881 into $190 000 to construct a research vessel, the R/V *Albatross* – the first large vessel designed specifically for oceanographic and fisheries research. "Like many other notable developments in the fields of fisheries, marine biology, and oceanography, the *Albatross* owed her origin to the vision and constructive imagination of Baird" (Coker, 1962). The construction of the *Albatross* was followed by the construction of the Fish Commission's permanent laboratory at Woods Hole. Baird established three areas of work for the Fish Commission: biological and oceanographic research; artificial propagation; and compiling and using fisheries statistics. Following Baird, George Brown Goode, a Smithsonian ichthyologist, was appointed Acting Commissioner in 1887. Goode formalized the organization of the commission under the three areas of work outlined by Baird, and this structure lasted until 1940. Although not in the original plans, fish culture in the Fish Commission received much public support and by 1883 consumed more than three-fourths of the Fish Commission's budget, leaving the biological research programme in the Division of Scientific Inquiry with a very modest budget (Goode, 1883).[2] Marshall MacDonald, who had been head of the propagation efforts, was appointed Commissioner in 1888, and fish culture became even more prominent.

WHAT IS FISHERIES OCEANOGRAPHY?

Fisheries science "is concerned with fluctuations in abundance of fisheries resources, the role of man in producing such fluctuations, and measures which can be taken to achieve and maintain optimum yields from these resources" (McHugh, 1970). Thus, fisheries science can be split into two areas: one involves understanding fluctuations in fisheries resources; the other involves managing the fisheries on these resources. Fluctuations in fisheries resources can occur because of changes in population size or in the availability of the population to the fishery (Sette, 1961). Fisheries oceanography, defined most broadly as "any kind of oceanography required for the appraisal or exploitation of any kind of organism useful to Man" (Blackburn as quoted by Sette, 1961), or "the study of oceanic processes affecting the abundance and availability of commercial fishes" (Wooster, 1961), relates to both causes of fluctuations.

The objective of one type of fisheries oceanography, which we term *operational fisheries oceanography*, is to understand the relationships of fisheries resources to the environment so fisheries can be prosecuted most effectively; this mainly involves using oceanographic information to predict the availability of fisheries resources. According to Laevastu and Hayes (1981), fisheries oceanography "is the study and application of oceanography, maritime meteorology and aquatic ecology to certain practical problems in fisheries. These practical problems are related to the productivity of the oceans or to the behaviour of various specimens, to the availability of fish and other fishable marine animals to the fisheries, and to the effects of oceanographic and meteorological conditions on the conduct of a fishery".

A second type of fisheries oceanography, which we will term *recruitment fisheries oceanography*, seeks to understand fluctuations in abundance of fishes, primarily through research on causes of variations in mortality of their young stages. Year-class strength is the most important biological variable facing fisheries managers (Rothschild, 1986). Fluctuations in abundance are usually caused by interannual variations in year-class strength. Year-class strength is generally established by the end of the planktonic egg and larval stages. Recruitment fisheries oceanography studies all aspects of the ecology of the young stages so as to understand the recruitment process and eventually to predict year-class strength.

A third area of research in fisheries oceanography examines the productivity of the ocean and its effect on fish stocks. Temporal and spatial variations in productivity on a variety of scales affect the distribution and abundance of fishes. Understanding decadal shifts in abundance of sardine and anchovy in eastern boundary current regions would be an example of this type of fisheries oceanography (MacCall, 1996). Studies into the carrying capacity of various oceanic areas for particular fishes would be another focus of investigation (Cooney and Brodeur, 1997).

By its very nature, fisheries oceanography involves large-scale, long-term, multidisciplinary investigations. While university scientists often participate in these studies, and many 'government' scientists also hold academic positions, the studies usually require the resources and commitments available only in national or international fisheries organizations. This paper focuses primarily on the development of recruitment fisheries oceanography in the US fisheries agency, although many of the concepts on which this discipline rests were developed in north-western Europe.

ORIGIN OF FISHERIES OCEANOGRAPHY

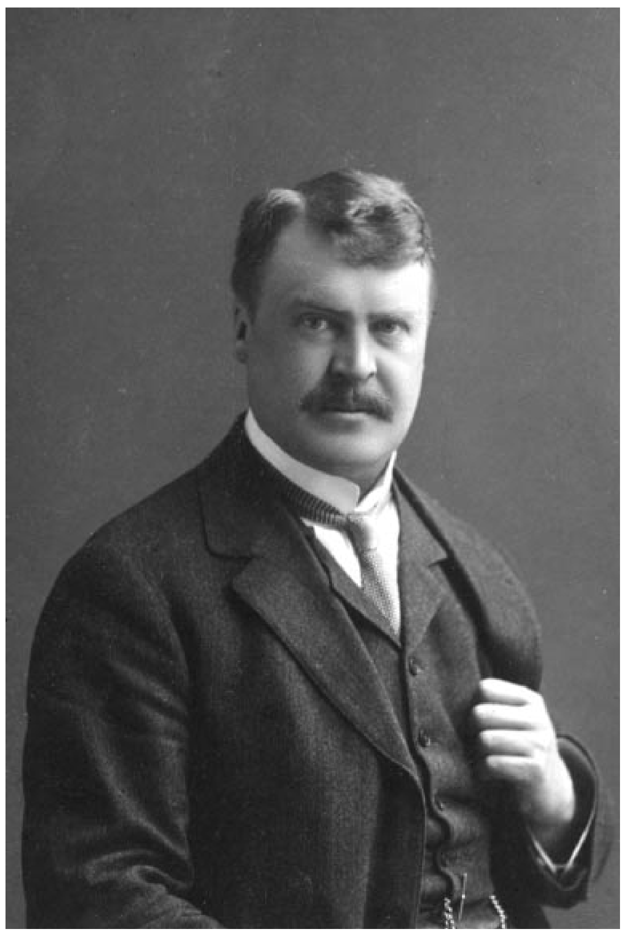
Fisheries oceanography can be said to have originated with the formation of the International Council for the Exploration of the Sea (ICES) in 1902 (Went, 1972). ICES was established following the Stockholm conference in June 1899, during which representatives of north-western European countries (Germany, Denmark, Sweden, Norway, the United Kingdom, Holland, Belgium, and Russia) realized that they could not understand and manage their fisheries without knowledge of the fish and their environment throughout their range. The delegates at the Stockholm conference proposed an initial 5-year programme for international exploration of the Arctic Ocean and the North and Baltic Seas in the interest of fisheries (Mills, 1989). "Their goal was to explain the fluctuations of such resources as the herring fishery, the cod fishery, and the great bottom fisheries, mostly plaice, by studying the life histories of the fish, their environmental requirements, and relating those requirements to the ever-changing physical and chemical environment of the North Sea" (Knauss, 1990). With participation of eight countries, ICES was a multinational effort to investigate environmental relationships of fishes of Northern Europe. Norway was represented by pioneers in their fields: Fridtjof Nansen (physical oceanography) and Johan Hjort (fisheries science). In the inaugural meeting, Hjort stated that the Norwegian government was involved "for the express purpose of obtaining practical results". Three committees were set up: a committee on fish migrations convened by Hjort, a committee on overfishing convened by Walter Garstang of the United Kingdom, and a committee on the Baltic convened by Nordquist of Finland. The purview of the migration committee (Committee A) was to develop an understanding of the interannual and decadal fluctuations in landings of fishes. At the time of the establishment of Committee A, the accepted hypothesis was that species (mainly Atlantic cod, *Gadus morhua*, and Atlantic herring, *Clupea harengus*) undertook large-scale migrations through the course of the year, and variations in the routes of these migrations affected local abundance and availability to fisheries. Actual abundance of the species was thought to be fairly constant; availability to fishermen was modified by distribution, which varied because of changing oceanographic conditions. Thus, although entitled the 'migration committee', this committee was actually concerned with reasons for fluctuations in fish abundance.

In spite of two major wars involving the member states on both sides of the conflicts, and all the changes that have occurred in the 20th Century, ICES remains a viable organization conducting cooperative research on a wide variety of topics related to the fisheries and oceanography of the region. As a result, the ecology of the north-east Atlantic is relatively well known. However, relating the physical environment to the abundance of fisheries, one of ICES' original goals, continues to be a subject of active research, and largely an enigma (Knauss, 1990).

ORIGIN OF RECRUITMENT FISHERIES OCEANOGRAPHY

Johan Hjort (Fig. 2) can be thought of as the father of recruitment fisheries oceanography. Although he was initially a proponent of the widely accepted migration hypothesis to explain fluctuations in fish abundance (Sinclair, 1997), through studies of age structure of fish populations, and the work of G.O. Sars (Sars, 1877),

Figure 2. Photograph of Johan Hjort. Supplied by Per Solemdal. Used with permission of the Institute for Marine Research, Bergen, Norway.



Johan Hjort
(1869–1948)

Birthplace:	Christiana (Oslo), Norway	
Education:	PhD,	University of Munich, 1892
Experience:		
	1893	Appointed Curator of University of Oslo Zootomical Museum.
	1894	Succeeded G.O. Sars as research fellow in Fisheries at the University of Oslo.
	1897	Appointed Director of University of Oslo Biological Station.

1900–14	Directed construction and research efforts of the R/V *Michael Sars*.
1906–16	Director of Fisheries for Norway; resigned in 1916 and went into self-imposed exile over Norwegian fisheries policy during World War I.
1902–08	Chairman of ICES Migration Committee.
1912	With John Murray, published classic book *The Depths of the Ocean*, based on cruises to the North Atlantic aboard the *Michael Sars* in 1910.
1914–15	Director of the Canadian Fisheries Expedition.
1916–21	In England; studied at Oxford University, where he was exposed to current ecological thought; inducted into Royal Society.
1921–48	Professor of Marine Biology at the University of Oslo.
1924–39	President of the Norwegian Whaling Committee.
1920–37	Vice-president of ICES.
1938–48	President of ICES.

The remarkable life of Johan Hjort has been documented by several authors (Ruud, 1948; Andersson, 1949; Solemdal and Sinclair, 1989). He remains as important a figure in fisheries thinking today as he was in the early 1900s, when he was instrumental in establishing the Board of Sea Fisheries in Norway, and the International Council for the Exploration of the Sea (ICES). His innovative thinking contributed to a paradigm shift in fisheries biology. As he began his work, it was widely considered that the abundance of sea fish was boundless, and fluctuations in catches were caused by variations in migratory patterns. Early in his career, Hjort realized that most fish populations were made up of several year classes, and their abundance was largely fixed during their early life. Differences in the sizes of year classes were responsible for most variations in abundance of fish populations. He came to these conclusions at a time when hatcheries in Norway were releasing eggs or young larvae into the ocean in an effort to increase stocks of fish. He realized that these efforts could not be expected to increase population size and he fought against them. It was many years before hatcheries both in Norway and the United States ceased these releases, based on Hjort's ideas and on lack of evidence of success (Solemdal *et al.*, 1984). Hjort was always an advocate for Norwegian fishermen, whether in discovering a large deepwater shrimp fishery, or in working on their behalf in international matters dealing with whaling. Based on work Hjort did in developing an accident insurance programme for fishermen, he pioneered the use of statistics in dealing with fisheries problems. Not only was Hjort concerned with fisheries, he was also deeply concerned with social issues and wrote extensively on the significance and rights of the individual. His strong convictions and ethics forced him to resign as Director of Fisheries in Norway and leave the country during World War I in a dispute over the government's decision to keep an international fisheries treaty secret. He used this period of self-imposed exile not only to increase his scientific skills, but to solidify his relationships with others in the international community concerned with fisheries matters. He was well served by this experience as he carried out his duties first as a Vice-president, and later as President of ICES, the position he held at the time of his death.

Hjort came to realize that these fluctuations were mainly caused by variations in the strength of year classes: "The rich year classes appear to make their influence felt when still quite young; in other words, the numerical value of a year class is apparently determined at a very early stage, and continues in approximately the same relation to that of other year classes throughout the life of the individuals" (Hjort, 1914). He further suggested the importance of food for newly hatched larvae and drift to nursery areas: "As factors, or rather events which might be expected to determine the numerical value of a new year-class, I drew attention to the following two possibilities:

1 That those individuals which at the very moment of their being hatched did not succeed in finding the very special food they wanted would die from hunger. That in other words the origin of a rich year-class would require the contemporary hatching of the eggs and the development of the special sort of plants or nauplii which the newly hatched larva needed for its nourishment.

2 That the young larvae might be carried far away out over the great depths of the Norwegian Sea, where they would not be able to return and reach the bottom on the continental shelf before the plankton in the waters died out during the autumn months of their first year of life" (Hjort, 1926).

Hjort came to these conclusions during the time when hatcheries were releasing enormous numbers of eggs and yolk-sac larvae into the sea in hopes of replenishing decreased populations. He fought hard, but largely in vain, to have sampling conducted to determine the value of these releases. Nevertheless, owing to his publications and work with ICES (from its beginning in 1902 until his death in 1948, at which time he was its president), his insight into the causes of fluctuations in the abundance of fishes has stimulated fisheries scientists throughout the 20th Century. As a result of Hjort's first hypothesis, the period when larvae are changing from getting nourishment from their yolk to when they must find food in the plankton became known as the 'critical period'. Expanding on this idea has been a central theme of fisheries oceanography since it was first proposed (May, 1974).

HJORT'S IDEAS CROSS THE ATLANTIC

In 1914 the Biological Board of Canada engaged Hjort to undertake a comprehensive investigation of Atlantic waters of the region of the Gulf of St Lawrence (the Canadian Fisheries Expedition: Hjort, 1919; Coker, 1962; Hubbard, 1993). This work gave Hjort opportunity to see if Altantic herring in the western Atlantic showed year-class variations similar to those

Figure 3. Photograph of Henry Bryant Bigelow. Supplied by Justine Gardner-Smith. Used with permission of Woods Hole Oceanographic Institution.

Henry Bryant Bigelow
(1879–1967)

Birthplace:	Boston, Massachusetts	
Education:	BA,	Harvard University, 1901
	MA,	Harvard University, 1904
	PhD in Zoology,	Harvard University, 1906
Experience:		
	1901–02	Sailed with Alexander Agassiz on a research cruise to the Maldive Islands.

1902–05	Sailed with Agassiz aboard the *Albatross* in the eastern tropical Pacific with visits to the Galapagos Islands, Easter Island, Mangareva in the Gambier group, and along the west coasts of South and Central America. Published reports on the medusae and siphonophores of the eastern tropical Pacific.
1912	At the suggestion of the famous Scottish oceanographer, Sir John Murray, Bigelow began a long-term study (lasting 12 years) of the Gulf of Maine.
1912–24	Conducted intensive study of oceanography, plankton and fishes of the Gulf of Maine aboard the US Bureau of Fisheries ship *Grampus.*
1927	Named curator of oceanography for the Museum of Comparative Zoology at Harvard University.
1927–37	Secretary for the newly formed Committee on Oceanography of the National Academy of Sciences which lead to the establishment of the Woods Hole Institution of Oceanography.
1931	Promoted to full professorship at Harvard University
1931	Published *Oceanography, Its, Scope, Problems, and Economic Importance*, a book based on reports of the Committee on Oceanography. This book set the course for the discipline in the United States for years to come.
1930–39	First Director of the Woods Hole Oceanographic Institution.
1927–68	Published 39 papers with W.C. Schroeder on fish (mostly elasmobranch) taxonomy.
1944	Appointed to be Alexander Agassiz Professor of Zoology at Harvard University.
1967	At the time of his death, Bigelow had served on the staff at Harvard University longer than any other person.

Henry Bryant Bigelow was a pioneer in combining biological and physical oceanographic studies and is remembered as "one of the founders of the new oceanography, that is, oceanography with an ecological aim…" (Graham, 1968 in Brosco, 1989). His scientific career can be subdivided into three phases in which he was an internationally recognized expert: cnidarian taxonomy, oceanography, and fish taxonomy (Graham, 1968). His publication record spans 66 years, and includes landmark publications in each of these fields. He is credited as being one of two individuals (along with William Beebe) most responsible for the development of oceanography in the United States in the period between World War I and World War II (Lyman, 1964). As secretary of the National Academy of Sciences' Committee on Oceanography, Bigelow played a key role in preparing the committee's report that persuaded the Rockefeller Foundation to donate $6 million toward the development of oceanography in the United States. The work of this committee during its 10-year span led to the establishment of the Woods Hole Oceanographic Institution and the Bermuda Biological Association, expansion of the facilities at Scripps Institution of Oceanography and to the establishment of the Oceanographic Laboratories at the University of Washington. Bigelow had learned old-style oceanography from Alexander Agassiz. As a 22-year-old senior at Harvard University, Bigelow accompanied Agassiz on his 1901 expedition to the Maldive Islands. He continued to sail with Agassiz until he earned a PhD in zoology in 1906 (Brosco, 1989). In 1912, as an assistant at Harvard University, he began a 12-year study on the biology and physical oceanography of the Gulf of Maine using the US Bureau of Fisheries ship R/V *Grampus.* The results of these studies were published by the Bureau of Fisheries as a series of three landmark monographs: physical oceanography, plankton, and fishes. In 1930, Bigelow became the first director of the Woods Hole Oceanographic Institution, and eventually was on the staff of Harvard University for longer than any other person. He was also a personal friend of Hjort and attended ICES meetings in Europe, where causes of fluctuations in abundance of fishes were discussed.

seen in herring from the eastern Atlantic. Hjort's crossing the Atlantic for this study would influence the direction of fisheries research both in Canada, primarily through his contacts with G.A. Huntsman, and in the United States, primarily through his contacts with Henry Bryant Bigelow (Fig. 3).

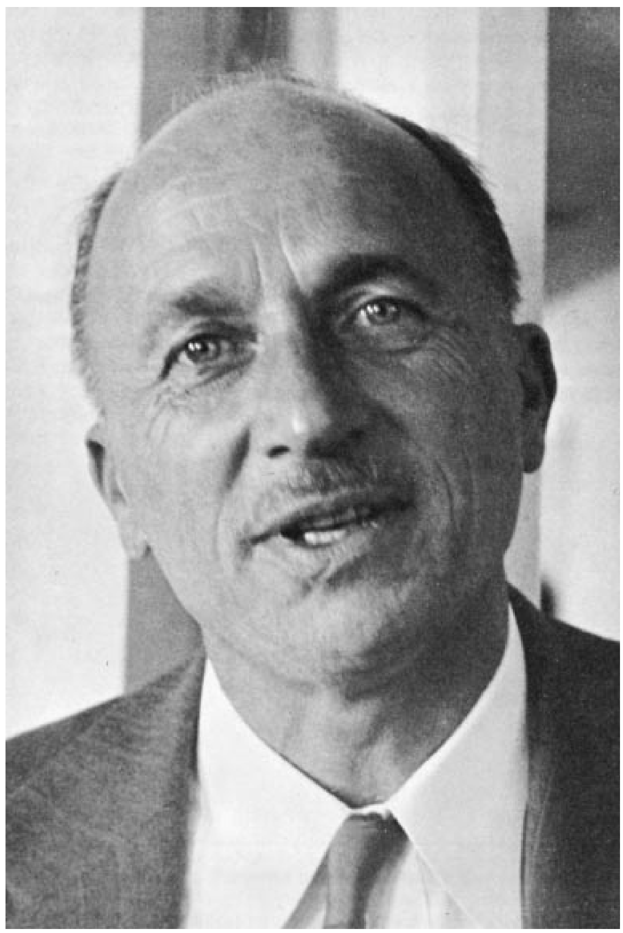
When Hjort arrived in Canada in 1915 to undertake the survey of fisheries resources, he found himself without needed instruments, but knew that Bigelow would have them in Boston, and that he could borrow them for his work (Hubbard, 1993). Hjort and his wife went to Boston to get the instruments and found Bigelow and his wife so congenial that they stayed for a week. During this visit, one can imagine that the subject of fluctuations in fish abundance was discussed. In letters, Hjort mentions that Bigelow discussed his Gulf of Maine studies during the visit, and it is highly probable that Hjort told Bigelow of his work and ideas on year-class fluctuations in fishes (Hubbard, 1993). Certainly Hjort's ideas are reflected in the research of two of Bigelow's later students, Lionel Albert Walford and Oscar Elton Sette.

RECRUITMENT FISHERIES OCEANOGRAPHY IN THE UNITED STATES

Atlantic mackerel

Although most efforts continued to concentrate on fish culture, as early as 1911 the US Bureau of Fisheries expressed interest in joining ICES in an effort to understand the causes of variability in catches of Atlantic mackerel, *Scomber scombrus*, which supported fisheries on both sides of the North Atlantic. Following Hjort's ideas on causes of fluctuations in fish abundance, the United States was to focus on early stages of mackerel in a cooperative research programme, but this effort was short lived, and in 1916 the United States withdrew from ICES (Smith, 1994).

Figure 4. Photograph of Oscar Elton Sette. Used with permission of National Marine Fisheries Service.



Oscar Elton Sette

(1900–1972)

Birthplace:	Clyman, Wisconsin	
Education:	BA in Zoology,	Stanford University, 1922
	MA in Biology,	Harvard University, 1930
	PhD in Biology,	Stanford University, 1957
Experience:		
	1918	Scientific assistant for W.F. Thompson, at the California State Fisheries Laboratory in San Pedro. His first job was to check canneries for albacore, *Thunnus alalunga*, landings.

1920–24	Assigned to State fisheries programme (Monterey, California) studying the Pacific sardine – life history habits and the effects of fishing on the resource.
1924–29	Chief of the Division of Fishery Industries (statistics), U.S. Bureau of Fisheries (Washington, D.C.)
1929–37	Chief of North Atlantic Fishery Investigations, U.S. Bureau of Fisheries, with Headquarters at the Museum of Comparative Zoology at Harvard University. During the summer months he acted as Director of the Bureau's Fisheries Station at Woods Hole.
1937–49	By Congressional mandate, Sette moved to Stanford to head a new program to study the California sardine fishery; there he was made Chief of the new South Pacific Investigations Program. Sette also served as the scientific advisor for the California Cooperative Sardine Research Program which became the California Cooperative Oceanic Fisheries Investigations (CalCOFI).
1949–55	Director of the new Honolulu Laboratory and Chief of the Pacific Oceanic Fishery Investigations (POFI).
1955–70	Chief of Ocean Research for the US Bureau of Commercial Fisheries at new laboratory on the Stanford campus. Founded Eastern Pacific Oceanic Conference (EPOC).

The professional life of Oscar Elton Sette, or Elton as he liked to be called, has been well documented by Powell (1972), and his activities are frequently mentioned in historical accounts of the CalCOFI programme (e.g. Scheiber, 1990). Sette's introduction to fisheries science came through his former high school chemistry teacher, Elmer Higgins, who hired him in 1918 at the age of 18 to check fish landings at California canneries. By 1920, Sette published his first paper, which dealt with the sardine fishery and mentioned interannual fluctuations in abundance, a theme that would pervade the rest of his career (Sette, 1920). Two years after graduating from Stanford in 1922, under David Starr Jordan's guidance, Sette began his career as a federal fisheries biologist for the US Bureau of Fisheries, taking a position in Washington, DC, as chief of the Division of Fishery Industries. He shortly found himself again working under Higgins, who had been appointed Chief of the Division of Scientific Inquiry. While he found his job of analysing fisheries statistics challenging, understanding fluctuations continued to intrigue him, and he was soon puzzling over variations in Atlantic mackerel landings. This interest was supported by Higgins and lead Sette to his doctoral work, and classic publication on the effect of the environment on larval survival, and ultimately year-class strength of Atlantic mackerel (Sette, 1943a). He conducted these studies as Chief of North Atlantic Fishery Investigations in a laboratory on the Harvard University campus. During this period, from 1928 to 1937, Walford was also studying at Harvard, and Sette and Walford acknowledged each other's help in their papers on mackerel and haddock recruitment. Sette mentions the editorial help of Walford in writing his papers. Walford used some of Sette's samples to establish the southern limit of larval haddock occurrence. While Walford did not cite Hjort's classic ideas on causes of variations in year-class strength, Sette actually quoted from Hjort. In 1937, the Bureau called Sette to return to California to lead its investigations into fluctuations in the sardine population, which supported a large and economically important fishery. The 12 years of Sette's tenure in this position, with Walford at his side, saw dramatic changes on many fronts. The country went from recovering from the Great Depression, through World War II, to the postwar boom, with California becoming an increasingly important presence on the national scene. The fishery, which had grown rapidly for the previous 20 years, peaked and started a precipitous decline. The federal role in investigation and management of the fishery went from being an unwelcome outsider to becoming a full partner with the State, and an organizer of what would become CalCOFI. Throughout this period, Sette maintained that to manage fisheries properly, the causes of fluctuations must be understood. Man's role through fishing could only be evaluated in the context of environmentally induced changes in abundance and distribution. He developed an exhaustive plan for studies in this regard which emphasized understanding the causes of mortality of young stages (Sette, 1943b). The list of Sette's coauthors during his time investigating the sardines reads like a who's who of fisheries science and oceanography: for example, E.H. Ahlstrom, J.C. Marr, J.D. Isaacs, and M.B. Schaefer. The long-term success of CalCOFI must be partially the result of the respect accorded to Sette for his organizational skills and scientific vision. After Sette was succeeded by Walford to continue the work in California on sardines, Sette went to Honolulu, Hawaii, where he studied the relationships between tuna distribution and oceanography. After 1955, he continued this work and expanded it to include other fisheries–oceanography interactions in a new laboratory established on the campus of Stanford University. Even after retirement in 1970, Sette continued his research as a rehired annuitant in charge of the Ocean Ecology group in Menlo Park, California.

In the late 1920s, while in charge of collecting and analysing catch data on mackerel off New England, Oscar Elton Sette (Fig. 4) became interested in understanding why they varied in abundance so much from year to year. This led Sette to conduct a study of their early life history in relation to the ocean environment off the Atlantic coast (Sette, 1943a). That the time was ripe for such ecologically based research is evident from comments made by Sette and others at the first US Bureau of Fisheries Divisional Conference, which was convened by Elmer Higgins in 1927 (Smith, 1994).

After a preliminary cruise in 1926, Sette collected eggs and larvae from 1927 to 1932 aboard the R/V *Albatross II*. His field work ended abruptly in June 1932 when the *Albatross II* was taken out of service as an economy measure. (Mackerel would be safe from having their eggs and larvae collected in any large-scale manner by federal fisheries biologists until over 30 years later, when in 1966 the R/V *Dolphin* conducted plankton surveys off the north-east Atlantic coast: Berrien, 1978.) Sette concluded, by measuring interannual changes in drift and mortality of cohorts of larvae, that increased mortality during the transition from yolk to exogenous food sources was not a major contributor to variations in mortality, but that variations in drift caused by winds seemed to be correlated with year-class strength. Thus, Sette rejected Hjort's first hypothesis (the critical period) but concurred with his second hypothesis (drift). This was a pioneering study in that population estimates of larval growth and mortality rates were computed.

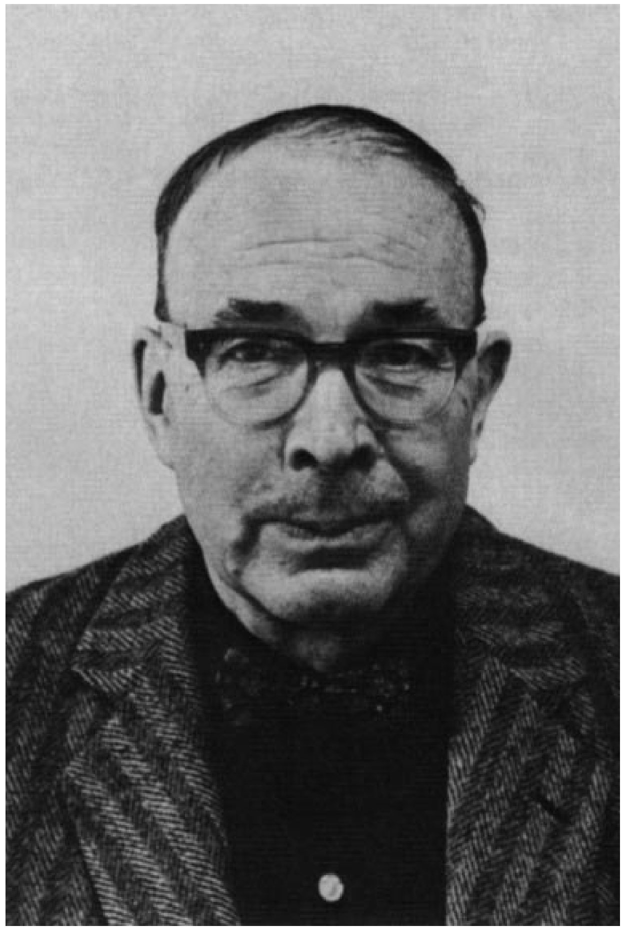
Haddock

Lionel A. Walford (Fig. 5) investigated the early life history of haddock, *Melanogrammus aeglefinus*, on Georges Bank (Walford, 1938). He justified this study by stating: "Judging from present studies of the Bureau of Fisheries, natural fluctuations in abundance of the American haddock over a wide area are due not to migrations of the adult population away from the fishing grounds but to actual changes in the numbers of fish. Furthermore, these changes do not usually affect the population as a whole but rather individual year broods, which, during the first year of their life, are subject to varying fortunes that determine their success or failure … the critical time when the success or failure of a year brood is determined occurs during the period of the embryonic, larval and post-larval stages … causes in fluctuations in abundance can be found by intensively studying the biology of these early stages and at the same time by observing changes in the environmental elements." Although Hjort's papers on the causes of fluctuations in fish abundance were not cited, it is evident from the above that Walford considered the same factors important. The basis of his study was collections of planktonic eggs and larvae made during several cruises aboard the R/V *Albatross II* in the Georges Bank area during 1931–32. He also used data collected by Sette in the same years, but farther south to Chesapeake Bay.Based on these collections and associated physical data, he postulated that interannual changes in drift patterns could carry variable amounts of eggs and larvae away from their nursery areas on Georges Bank. Extensive recent work by the federal fisheries agency and others on haddock early life history and fisheries oceanography has followed this pioneering work of Walford (Chase, 1955; Colton and Temple, 1961; Koslow *et al*., 1985).

Pacific sardine

Pacific coast fisheries matters were under the influence of William F. Thompson (Fig. 6) when concerns in the early 1930s over declining catches of Pacific sardines, *Sardinops sagax*, off California caused the California Department of Fish and Game to seek regulations limiting the fishery. The industry was influential in getting the federal government involved in studies to determine the cause of these declines: was it overfishing or was it natural fluctuations in abundance? "The ship operators … resorted to a plan (used before and since) by which … legislation could be postponed by asking for a special study of the abundance of sardines…" (Scofield, 1957; quoted in Radovich, 1982). Sette, a former California Department of Fish and Game employee under Thompson, was detailed to California by the federal government in 1937 to work with other fisheries scientists to investigate the decline (Powell, 1972, 1982). Sette shortly presented a plan for the study of all aspects of the life history of the sardine, in relation to the fishery (Sette, 1943b). This plan, which included ecological studies on all life history stages, as well as studies on the impact of the fisheries, was in stark contrast to the more narrowly focused research that would have been advocated by Thompson. The active participation of the Scripps Institution of Oceanography through Harald Sverdrup, a Norwegian oceanographer familiar with ICES studies, and Roger Revelle, assured that the programme would have a broad ecological base. Although each participating agency had its own agenda, a working relationship was established, and in 1947 the California legislature established the Marine Research Committee (MRC) with representatives of the industry, several scientific agencies, and with Sette as scientific advisor (Baxter, 1982; Radovich, 1982). The MRC developed the California Cooperative Sardine Research Program, which in 1953 was renamed the California Cooperative Oceanic Fisheries Investigations (CalCOFI). CalCOFI has been the largest and most long-lasting of the fisheries oceanography studies in which the federal fisheries agency has participated

Figure 5. Photograph of Lionel Albert Walford. Used with permission of the American Fisheries Society.



Lionel Albert Walford
(1905–1979)

Birthplace:	San Francisco, California	
Education:	BA,	Stanford University, 1929
	MA,	Harvard University, 1933
	PhD,	Harvard University, 1935
Experience:		
	1926–27	Biologist, International Fisheries Commission, U. S. and Canada; Terminal Island, California.
	1927–31	Senior Fisheries Researcher, Division of Fish and Game of California/Bureau of Commercial Fisheries; Terminal Island, California.
	1931–35	Graduate Student, Harvard University.
	1935–36	Wrote "*Marine Game Fishes of the Pacific Coast*..." and taught at Santa Barbara State College.
	1936	Assistant Aquatic Biologist, U.S. Bureau of Fisheries (New Orleans – Woods Hole).
	1937	Associate Aquatic Biologist, U.S. Bureau of Fisheries, Stanford University.
	1945–47	Assistant Chief of the Division of Information, Fish and Wildlife Service, Washington, D.C.

1947	Aquatic Biologist, Fish and Wildlife Service, Cambridge, Massachusetts.
1948	Chief, Section of Marine Fisheries, Fish and Wildlife Service
1948–57	Chief of the Fishery Biology Branch, Fish and Wildlife Service.
1957–60	Chief Atlantic Fishery Oceanography Research, Bureau of Commercial Fisheries.
1960–71	Director of the Bureau of Sport Fisheries and Wildlife's Sandy Hook Laboratory, Highlands, New Jersey.

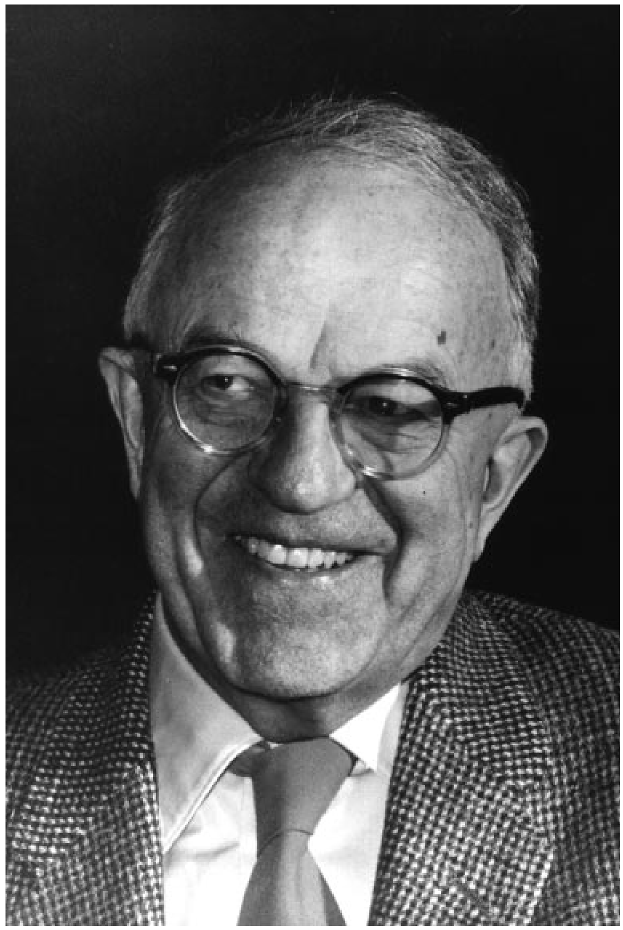
Lionel Albert Walford, or Bert as he was called by friends and close associates, began his career in fisheries in 1926 while a student at Stanford University. After graduating from Stanford, he went to Harvard University to work on his advanced degrees under Bigelow, who was exploring the physics and biology of the Gulf of Maine. Walford's thesis on recruitment of haddock was an innovative study for its time. Hjort maintained that the effects of the environment on survival of early stages of fish were largely responsible for fluctuations in year classes, and his influence on Walford's work is clearly seen. That Bigelow passed Hjort's ideas on to Walford is evident in the introduction to the paper on haddock recruitment that resulted from Walford's thesis research, although he did not cite Hjort's studies. As he was finishing his studies at Harvard, during the depths of the Great Depression, Walford agreed to participate in a cruise aboard a private yacht to survey and write a book on the game fishes of the Pacific coast of North America. The resulting landmark book was published, with splendid colour illustrations of the fishes, while Walford was teaching at Santa Barbara State College. Shortly thereafter, Walford began his career as a federal fisheries biologist back on the US east coast at Woods Hole, MA. Within a few months Walford accompanied Sette, who was with him during his Harvard days, back to California to establish the federal investigations on the causes for the decline of sardines. Walford took over these investigations after Sette left, but within a few years was called to Washington, DC. Walford was soon named Chief of the Marine Fish Section, and later Chief of the Fishery Biology Branch, where he wielded considerable influence in increasing the professionalism and broadening the scope of the research.

Throughout Walford's career, he promoted studies to increase understanding of the basic biology and ecology of fishes, thinking that successful management must be based on such an understanding. He was an excellent communicator, and encouraged those with whom he worked to write well and to present their scientific results clearly. Sometimes this led to innovative illustrations, such as what became known as the Walford plot, a way of graphically comparing age and growth data. He continually sought patterns in nature and produced large-scale maps of many variables to illustrate geographical differences in the physics and biology of the oceans. A favourite concept was to look for the 'big picture' (i.e. the larger-scale implications of a particular phenomenon or event). His publications were designed to reach a broad audience, not just his scientific colleagues. He, along with the more famous Rachel Carson, with whom he worked for a number of years, was an early evangelist for wise stewardship of marine life. His book *Living Resources of the Sea* outlined his ideas for investigations required to develop an understanding of marine life, so as to use it wisely (Walford, 1958).

Walford continually challenged the status quo of fisheries investigations in the federal government as being too narrow. Following establishment of a marine game fish programme in the Bureau of Sport Fish and Wildlife, Walford was named director of its new laboratory at Sandy Hook, NJ, where he served until he retired in 1971. There he was given considerable freedom to implement his ideas, and he recruited a cadre of newly graduated biologists who had university training in fishery science but little or no experience in the federal government. The immediate objects of the studies were the marine game fish of the US east coast, and a full range of investigations into their biology was initiated. Much valuable insight into the lives of these fish was gained, although some studies were not carried to the degree of completion envisioned by Walford. Many in Walford's initial cadre moved on to various fisheries research organizations throughout the country, carrying his vision with them. Maybe the times have caught up with Walford's ideas independently, but fisheries science is much more broadly based and ecologically orientated now than it was when Walford first expressed these ideas.

(Scheiber, 1990). From the beginning, the programme had a broad emphasis: to study the sardine and its environment, and the effects of fishing on the species. Six areas of study were mentioned in early planning documents: "1. Physical-chemical conditions in the sea. 2. Organic productivity of the sea and its utilization. 3. Spawning, survival, and recruitment of sardines. 4. Availability of the stock to the fishermen (behaviour of the fish as it affects the catch) – abundance, distribution, migration, behaviour. 5. Fishing methods in relation to availability. 6. Dynamics of the sardine population and fishery" (Miller, 1948, quoted in Scheiber, 1990). This programme involved collecting large amounts of physical and biological data over a huge section of ocean off the US west coast (Hewitt, 1988). As the sardines continued to decline and the fishery ceased, CalCOFI broadened its objectives to include more species and larger-scale

Figure 6. Photograph of William Francis Thompson. Supplied by Marcus Duke. Used with permission of the University of Washington, School of Fisheries.



William Francis Thompson
(1888–1965)

Birthplace: St Cloud, Minnesota

Education:

BA,	Stanford University, 1911
PhD,	Stanford University, 1930

Experience:

1906–09	Studied zoology under Trevor Kincaid at the University of Washington.
1911	Surveyed clam and oyster beds for California Department of Fish and Game.
1912–13	Surveyed clam and oyster beds of British Columbia during summers.
1914–17	Investigated British Columbia halibut fishery; used fishermen's logbooks to obtain catch information.
1917–23	Conducted fisheries research programme for California Fish and Game Commission, and became Director of the California State Fisheries Laboratory.
1924–37	Organized and directed research on Pacific halibut for the International Fisheries Commission (IFC, later to become International Pacific Halibut Commission).
1930–48	Research professor and head of Department of Fisheries, University of Washington (half-time with other half devoted to IFC).

1937–43	Directed research of the newly formed International Pacific Salmon Fisheries Commission.
1943–47	Assumed full-time directorship of University of Washington School of Fisheries.
1947–58	Established and served as first Director of University of Washington Fisheries Research Institute.

Fisheries science off the U.S. Pacific coast in the early 1900s was dominated by William F. Thompson, who worked on fisheries all along the Pacific coast, including those for albacore, Pacific sardine, Pacific halibut, *Hippoglossus stenolepis*, and Pacific salmon, *Oncorhynchus* spp. (Van Cleve, 1966; Stickney, 1989; Scheiber, 1994). As a leader in the School of Fisheries at the University of Washington from 1930 to 1958, his influence extended to a whole generation of fisheries biologists. As head of the International Pacific Halibut Commission when it was co-located with the federal fisheries laboratory in Seattle from 1931 to 1936 (Atkinson, 1988), he strongly influenced federal fisheries research as well. As a result of his studies, and given the urgency of recommending management options and the limits of funds available for research, Thompson advocated studying the fisheries themselves, rather than fish ecology, to develop means for managing them. He felt that abundance of fish stocks would be correlated with catch rates. In his own words, Thompson noted that it was better to tunnel the mountain than remove it in its entirety to understand the effects of rate of fishing on catch and abundance (Thompson, 1922). This was in sharp contrast to the ecological thinking that had developed in north-western Europe, and which was being pursued by Sette and Walford. Early in his career, Thompson worked for the California Department of Fish and Game on causes of fluctuations in abundance of sardines and examined effects of fishing and the environment. Besides undertaking extensive studies of catch records and age composition and conducting tagging studies, Thompson directed descriptive studies of Pacific halibut early life history (Thompson and Van Cleve, 1934). The continued successful fishery for Pacific halibut is raised as evidence of the value of Thompson's management strategy of controlling the catch levels in response to variations in catch rates, and during his career accorded him considerable political clout and approval from the industry. However, his thesis that variations in abundance were the result of fishing pressure rather than environmental factors led to one of the most contentious debates in the history of fisheries science (Skud, 1975). His work with both Fraser River and Bristol Bay sockeye salmon, *Oncorhynchus nerka*, is credited with continued successful fisheries in both areas. The semelparous, anadromous life history pattern of salmon requires special assessment and management techniques and precludes studies of oceanographic effects on egg and larval stages. Thompson felt that events during the freshwater period of young salmon were more important in determining year class size than events early in their ocean existence (Thompson, 1959). Recently, with increased hatchery production of salmon, questions of the ocean carrying capacity and how it varies have become topics of concern to fisheries oceanographers (Cooney and Brodeur, 1998).

oceanographic processes. Such luminaries in fisheries oceanography as Elbert Halvor Ahlstrom (Anonymous, 1979) and Reuben Lasker (Longhurst, 1988; Hunter, 1989) continued the federal involvement in CalCOFI begun by Sette and Walford. Lasker (1965) stated his view of the goal of the federal involvement succinctly: "Ultimately we hope to be able to predict what the effect of the environment is on spawning success". Northern anchovies, *Engraulis mordax*, seemed to replace sardines as the dominant small coastal pelagic fish of the California Current. The impacts of large-scale circulation variations on the California Current became appreciated, starting with the 1957–58 El Niño. Understanding the causes of fluctuations in abundance of sardines, including the role of humans, continued to be an elusive goal (Marr, 1960; Radovich, 1960; Murphy, 1961). The issue was complicated by finding that there were several stocks of sardines with separate centres of distribution and seasonal migratory patterns. The relation between the anchovy and sardine was open to much speculation: Were they competitors at some stage in their life history? As adults? As larvae? Did one prefer slightly different oceanographic conditions from the other? Did cooler temperatures favour anchovies? Were sardine numbers reduced by fishing to a point that anchovies could 'take over'?

1950–1970

As CalCOFI was becoming well established, the federal fisheries agency undertook other smaller, less ambitious fisheries oceanographic studies. For example, "In 1953, the Fish and Wildlife Service inaugurated a program to study the early life history of haddock in the Gulf of Maine in an attempt to relate spawning location and the pattern of drift to the success of year class. The R/V *Albatross III* made cruises during the spring of 1953, 1955, 1956 and 1957" Colton (1964). On the basis of these cruises, Colton and Temple (1961) "concluded that under average conditions most fish eggs and larvae were carried away from Georges Bank and that only under unusual hydrographic conditions were eggs and larvae retained in the area" (Colton, 1964).

From January 1953 to December 1954, nine cruises were also conducted off the south-east coast of the US aboard the M/V *Theodore N. Gill* to "ascertain the potential productivity of those waters adjacent to our coast from Cape Hatteras on the north to the Florida Straits on the south" (Anderson *et al.*, 1956). From 1965 to 1968 a survey of eggs and larvae of fishes off the east coast was conducted during 12 cruises aboard the R/V *Dolphin* to establish offshore distribution patterns of eggs and larvae of fish that are estuarine dependent as juveniles (Clark *et al.*, 1969, 1970). Although both of these programmes added to our knowledge of the early life history of numerous species along the Atlantic coast, they fell short of their ambitious goals, partly because the survey activities were not followed by detailed hypothesis-driven studies. However, for some species encountered during these studies, hypotheses were developed to explain variation in recruitment (e.g. bluefish, *Pomatomus saltatrix*, Kendall and Walford, 1979; Atlantic menhaden, *Brevoortia tyrannus*, Nelson *et al.*, 1977) which have led to additional focused studies.

Discussions in 1968 among several federal scientists from around the country involved in early life history studies resulted in a nationwide programme: Marine Resources Monitoring, Assessment, and Prediction (MARMAP). Among its several goals, this programme intended to standardize collection of fish egg and larval data as well as environmental data and "to determine seasonal and annual variability in biological and environmental components of the shelf ecosystem that influence the size of recruiting fish populations" (Sibunka and Silverman, 1984). Although many primarily field studies were carried out in several areas under the MARMAP banner in the following decade, few went beyond basic descriptions of spatiotemporal distribution of fish eggs and larvae. The accumulation of such data became the goal in itself. One of the impediments to more detailed ecological studies was the lack of involvement of physical scientists. Nevertheless, MARMAP sampling off the US east coast documented the dramatic increase in abundance of sand lance (*Ammodytes* spp.), and the concomitant decrease in abundance of Atlantic herring, along with seasonal cycles in lower trophic levels that influence larval fish feeding success (Sherman *et al.*, 1984).

1970–1995

In 1970 the National Oceanic and Atmospheric Administration (NOAA) was formed and included the federal fisheries agency (renamed the National Marine Fisheries Service – NMFS), and federal laboratories investigating the ocean environment. This provided the administrative structure to allow interdisciplinary studies such as are required in fisheries oceanography. In 1976, passage of the *Magnuson Fisheries Conservation and Management Act* gave NOAA responsibilities for providing scientific data to manage ocean fisheries within 200 miles of the US coast.

Under this mandate and administrative coordination, several large-scale interdisciplinary NOAA programmes have investigated recruitment processes of several economically important fish stocks such as Atlantic cod and haddock in the Georges Bank area, Atlantic menhaden, *Brevoortia tyrannus*, and other estuarine-dependent species off the south-east Atlantic states, and walleye pollock, *Theragra chalcogramma*, in Alaskan waters. Off California, sardines became more abundant in the 1990s than in the 1970s–1980s (Wolf, 1992), providing CalCOFI opportunities to use recently developed techniques to gain an understanding of their population dynamics.

Attempts to expand on (e.g. Lasker, 1975: stable ocean hypothesis; Cushing, 1975: match/mismatch hypothesis) or to replace (e.g. Miller *et al.*, 1988: bigger is better hypothesis; Sinclair, 1988: member-vagrant hypothesis) the hypotheses of Hjort did not prove wholly satisfactory. During the early 1980s, several fish ecology workshops held in the United States (e.g. Rothschild and Rooth, 1982) identified understanding processes affecting recruitment to fisheries as a topic of great scientific and practical importance. Technological advances during this period, such as the discovery of daily growth increments on larval fish otoliths (Brothers *et al.*, 1976), development of laboratory rearing procedures and subsequent laboratory studies on physiology and behaviour of larvae under controlled conditions (Blaxter, 1986), and the use of satellites to track surface features of the ocean (Vastano *et al.*, 1992), held great promise for gaining understanding of recruitment processes.

CONCLUSIONS

Although much information has been gathered and analysed and numerous publications completed, understanding recruitment remains an elusive goal, just as it was when Baird first directed research in the Fish Commission in 1871. Some (Walters and Collie, 1988) have even suggested, as Hjort himself did to ICES (Sinclair, 1997), that understanding recruitment processes is not worth the effort; managers merely need estimates of recruitment strength. Just correlating year-class strength with environmental variables is not enough: a true understanding of the processes involved in variations in survival of young stages, as Baird advocated, is required. "Since the 1920s, correlations of the strength of year classes with environmental factors … began to take a certain melancholy consistency. Initial data might suggest a high correlation … but eventually the correlation would fail" (Smith, 1994).

Could the founders of recruitment fisheries oceanography have anticipated the complexity of the recruitment process when they first advocated an ecological approach to the study of fluctuations in fish populations? Even with the increased awareness of the importance of fish recruitment, and recent technological and conceptual advances, many of the questions and hypotheses they posed remain unanswered.

ACKNOWLEDGEMENTS

This paper benefited immeasurably from encouragement and comments by several people, most of whom have more intimate knowledge of this subject than we: some were active participants in formulating the ideas and implementing the research that we discuss. Among these were John Clark, former Deputy Director of the Sandy Hook Laboratory; Warren Wooster, Professor Emeritus, University of Washington; Clint Atkinson, former Director BCF Seattle and Beaufort Laboratories; Harry Scheiber, University of California, Berkeley; Paul C. Thompson, former Director of Research, BCF; Tim Smith, NMFS Woods Hole Laboratory; Willis Hobart, head of Office of Scientific Publications, NMFS; Jean Dunn, NMFS Seattle Laboratory (retired); and Michael Sinclair, Bedford Institute of Oceanography, Nova Scotia. We appreciate all of their help, but take full responsibility for the material we included and our interpretations.

NOTES

1. In 1903 the US Commission of Fish and Fisheries became the US Bureau of Fisheries in the Department of Labor and Commerce. In 1913 the departments of Labor and Commerce separated, and the Bureau of Fisheries was included in the Department of Commerce. In 1939 the Bureau of Fisheries was transferred to the Department of the Interior, and in 1940 the Fish and Wildlife Service was formed in the Department of the Interior by combining the Biological Survey from the Department of Agriculture with the Bureau of Fisheries. In 1956 the US Fish and Wildlife Service, composed of the Bureau of Commercial Fisheries and the Bureau of Sport Fisheries and Wildlife, was established within the Department of the Interior. In 1970 the Bureau of Commercial Fisheries returned to the Department of Commerce and was renamed the National Marine Fisheries Service. In 1970 the National Marine Fisheries Service became part of the newly formed National Oceanic and Atmospheric Administration within the Department of Commerce, where it remains today.

2. In 1877, G.O. Sars reported that he had artificially fertilized eggs of Atlantic cod and followed their development through hatching (Sars, 1877). He also raised the question of whether artificial hatching of fish might be used to "prevent the occurrence of unfavourable years". Baird had this Norwegian paper translated into English and he succeeded in artificially hatching cod eggs at Gloucester, MA in 1878. Captain G.M. Dannevig founded a cod hatchery in Flødevigen, Norway, in 1882 with private funds, and visited the United States in 1883 to observe their methods of cod culture. On returning to Norway, Dannevig proposed to financial backers that he would construct a "hatchery after the American model" and the hatchery was completed in February 1884.

Although not in the original plan for the work of the US Fish Commission, propagating fish soon became its major activity. In 1870, the year before the Fish Commission was established, a private organization, the American Fish Culturist Association (AFCA, renamed the American Fisheries Society in 1886), was formed (Thompson, 1970). In early 1872 the AFCA lobbied Congress to establish federal fish hatcheries. Although Baird had earlier rejected this idea, he now actively promoted it, and in June 1872 a bill appropriating monies for hatcheries became law. The AFCA wanted the federal government to establish populations of desirable freshwater fish (such as trout) throughout the country, while Baird viewed the hatcheries as a way to dampen fluctuations in abundance. Culture of freshwater fish was emphasized during the first few years. Carp from Germany were shortly thereafter introduced throughout the country, and shad were introduced to west coast rivers from the east coast. Fish propagation was very popular and appropriations were soon three times the amount for all other activities of the Commission, justified by the idea: "... it is better to expend a small amount of public money in making fish so abundant that they can be caught without restriction ... than to expend a much larger amount in preventing the people from catching the few that still remain" (Goode, 1883). Following successful breeding of cod and haddock in 1878, propagation of marine fish became an increasingly large part of the culture efforts (Earll, 1880; Brice, 1898). The first laboratory of the Commission, at Woods Hole, MA, was built as a hatchery in 1885, and was quickly followed by laboratories at Boothbay

Harbor, ME, and Gloucester, MA (Becker, 1991). The first two ships of the Commission, the R/V *Grampus* and the R/V *Fish Hawk*, were floating fish hatcheries. From 1872 to 1940, over 65% of the budget went to hatcheries, during which time over 200 billion fish eggs and fry were released. By 1940, 98% of the eggs and 75% of the fry were of marine species. Cod, haddock, winter flounder and lobster were the primary marine species cultured. At the height of hatchery operations, in 1929, over 2.5 billion cod eggs alone were released. The effectiveness of culturing marine fish was never objectively demonstrated, and the last hatchery activities ceased in 1952. "Hatchery production of marine commercial fish species was terminated in 1952 since research had failed to disclose that worthwhile benefits were obtained from such stocking" (Duncan and Meehan, 1954).

Rather than rearing marine fish to a size larger than when most natural mortality occurs, their eggs and early larvae were released into the sea (techniques to rear marine fish beyond the yolk-sac stage were not perfected until the early 1960s; Shelbourne, 1964). The premise upon which this practice was carried out was that there is a strong correlation between the number of eggs produced and the number of young recruited to the population. This idea was seriously questioned by Hjort in Norway and by most British fisheries scientists of the day (Shelbourne, 1965). With the enormous fecundity of most marine fish, extreme mortality must occur during these egg and early larval stages. In Norway, experiments failed to prove beneficial effects of releasing eggs and early larvae of cod, but such experiments were not conducted in the USA (Solemdal *et al.*, 1984). Rather, the Fish Commission relied on hearsay accounts of increased numbers of fish after eggs had been released. For example, the large numbers of young cod caught in Gloucester Harbor, MA, 5 years after culture efforts had started were referred to locally as 'Commission cod'.

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