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IMPACT OF THE USE OF METEOROLOGICAL AND CLIMATOLOGICAL DATA ON FISHERIES AND AQUACULTURE

Submitted by
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Report of the CAgM Joint Rapporteurs on the Impact of the Use of Meteorological and Climatological data on Fisheries and Aquaculture

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ABSTRACT

The Commission for Agricultural Meteorology (CAgM) at its 12th Session held in Accra, Ghana, 18-26 February 1999, established Joint Rapporteurs on the Impact of the Use of Meteorological and Climatological Data on Fisheries and Aquaculture. The terms of reference for the Joint Rapporteurs include the following:

(a) To survey and summarize the existing uses of meteorological and climatological data on fisheries and aquaculture;

(b) To describe, using case studies from Member countries, the impacts of such information;

(c) To suggest ways and means to improve further agrometeorological information for applications in fisheries and aquaculture;

(d) To submit mid-term information on the progress of activities of the joint rapporteurs and a final report to the president of the Commission not later than six months prior to the next session of the Commission.

This report was prepared by the joint rapporteurs, Ngo Sy Giai from the Agrometeorological Research Centre, Institute of Meteorology and Hydrology, Vietnam and Paul Taylor from the National Institute of Water and Atmospheric Research, New Zealand.

There are two sections of this report. The first section gives an overview of the relationship between climate and fisheries and aquaculture in China and Vietnam. Specifically, the first section elaborates on the distribution of various freshwater and saltwater aquatic resources, the various climate related issues involved in aquaculture such as raising fish in pools, prawn farming, pearl farming, and harvesting open-water and artificially-raised fish, and the transportation and processing of aquatic products. The section concludes by discussing the various climatic problems with aquaculture and listing some requirements of using hydrometeorological and environmental information to serve aquaculture. There are also some recommendations on how to strengthen the capability in providing hydrometeorological and environmental information for aquaculture production.

The second section gives an overview on the data needs for fisheries and aquaculture in New Zealand. The topics include: a brief overview of the freshwater and saltwater environments in New Zealand; the various meteorological data used in New Zealand for fisheries including information on the Southern Southern Oscillation Index (SOI) and the Pacific Decadal Oscillation index (PDO); the uses of the data in monitoring access to fisheries; monitoring environmental impacts; predicting fish distribution; and discusses and several case studies.

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APPLICATION OF HYDROMETEOROLOGICAL AND ENVIRONMENTAL CONDITIONS IN AQUACULTURE

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1.1 RELATIONSHIP BETWEEN CLIMATE AND FISHERIES

1.1.1 Distribution of Aquatic Product Resources

The resources are associated with latitude, elevation, water - area formation, flow direction in rivers, oceanic current, weather, climate, and human interference. In reference to adaptiveness, aquatic creatures can be fit for different temperature regimes: cold, cold-to lukewarm, lukewarm, lukewarm-to-warm, and warm.

1.1.2 Distribution of Freshwater Fish Species

Table 1 gives the freshwater fishes distribution consisting of the northern, eastern, southern and western parts of the China in addition to the Ningxia - Inner Mongolia area with the indicative fishes and the natural environment for each of the regions (China Meteorological Press, 1993).

Table 1. Representative freshwater fishes and the related climate for each of the regions of China

Region	Climatic zone	Ecological adaptiveness	Indicative fish
Northern	Northern and mid temperate	1) Cold water 2) Northern	Grayling Fam., Salmon Fam., *Esocidae*, *Gadus macrocephalus*, *Cottidae*
Western	Major region of frigid Qinghai - Xizang plateau at elevation > 700m	1) Cold water 2) Local	*Cobitis teania* subfam. (*Misgarnus anguillicaudatus* categ. of scaleless round - bodied species) *Pungitius sinensis* (nine - spined stickleback)
Ningxia - Mongolian	Major arid climate of Northwest China	1) Cold - lukewarm 2) Ancient	Graining subfam., *Cobitis taenia* subfam. (*Misgarnus anguillicaudatus*), *Gasterosteidae*
Eastern	Southern temperate, Northern and mid subtropical	1) Lukewarm water 2) Still water	Subfamilies of *Parabramis pekinensis*, *Xenocypris argentea*, *Hypophthalmichthys molitrix*, *Siniperca* (containing no *Acrossocheilus fasciatus* or the species < 1/5 those of *Cyprinus carpio*)
Southern	Southern subtropical, Northern tropical	1) Warm water 2) Southern	*Acrossocheilus fasciatus* (with species > 1/5 those of *cyprinus carpio*), *Biforate Cyprinus carpio Homalopteridae*, *Liobagrus styani, Euchiloglanis davidi.*

1.1.3 Distribution of Freshwater Farming Products

In China, many of the cultured freshwater fishes belong in the category for lukewarm water. *Ctenopharyn odon idellus, Cyprinus carpio, Carassius auratus, Hypophthalmichthys molitrix* and *Aristichtys nobilis* are most popular, *Mylopharyngodon piceus* are limited to the basins of Changjiang and Zhujiang Rivers, where *Bellamya purificata* and *Corbicula* are available, and *Cirrhina molitorella* and some tropical fishes raised only in the South because of the adaptiveness to warm water. In contrast, Salmon gairdneri are bred only in the North, e.g., Beijing area and Shanxi province.

1.1.4 Distribution of Ocean Fish Species

The distribution of sea fisheries depends on the weather conditions and current status in the sea. For example, the Huanghai and Bohai Seas of China are dominated by *Pseudosciaena polyactis, P. arocea* and *Trichiurus haumela* for lukewarm-to-warm water, making up more than 50% of the total resources there, next to which are warm water fishes like *Ilisha elongata*, *Stromateoides argenteus* and *Pneumatophorus japonicus*. In summer, on the other hand, in the depth of the Huanghai Sea there are masses of cold water, which spread in winter into the north of the East China Sea, expanding the domain of cold - lukewarm fishes as the only area for cold water fisher in China, among which *Gaclus macrocephalus*, *Cleisthenes herzensteini*, *Limanda yokohamae*, *Paralichthys olivaceus* and Huanghai Sea Clupea harengus (*Mylopharyngodon piceus*) are typical in the northern part of the central Huanghai Sea.

The different conditions between the eastern and western parts of the East China Sea result in the difference in the fish distribution, with warm water fishes dominant in the western waters from the Changjiang River mouth to the Taiwan Straits, especially south of the Zhoushan Islands, where are found all the fish categories in the Huanghai Sea. Famous for its four types of ocean products (*Pserdosciaena polyactis, P. arocea, Sepia esculenta* and *Trichiurus lepturus*), the Zhoushan fishery ranks first in the output for the country. In this part the warm water resources come next, and fish of cold-to-lukewarm adaptiveness (e.g. some kinds of right-eyed flounders) account for a very small portion. The eastern part of the Sea covers a region south of Kyushu via the Ryukyu Islands to the Northern end of Taiwan, in which warm water fishes like *Chaetodon modestus, Labricae*, and *Muraenidae* are dominant with a very small portion of lukewarm-to-warm water varieties and almost none of cold-to-lukewarm water fishes.

Differences in fish variety exist between the southern and northern parts of the south China Sea. *Nemipterus virgatus, Scopeliformes, Lutianus erythropterus, Decapterus maruadsi*, and *Sardinella* are dominant in the northern part including the offshore area and Beibu Gulf (Tonkin) while in the southern part covering the area south of the Hainan and Taiwan Islands, and the neighborhood of the Dongsha, Zhongsha, Xisha and Nansha Islands, the fisheries all belong in warm water categories.

East of the Taiwan are the tropical waters of the western Pacific, which is the passage of Kuroshio so that there are fish groups travelling with the warm current in any of the seasons, e.g., *Thunnus tonggol, Cypselurus arcticeps, Chaetodon modestus, Katsuwonus pelamis, Euthynnus yaito*, etc.

1.1.5 Aquaculture and Climate

Freshwater farming takes the main part in the aquaculture. However, in recent years, salted freshwater (with 1 - 24% salinity) and seawater breeding has been developed rapidly. Freshwater farming can be done in pools, ponds, reservoirs, lakes, and rivers. The other two forms are carried out in harbors, seawall areas, and salinas. Besides, aquatic plants are raised in offshore waters. Some forms of aquaculture are outlined below.

1.1.5.1 Raising fish in pools

This form takes the largest portion of freshwater farming in many countries (including China and Asian countries) with fishes including *Hypophthalmichthys molitrix, Aristichtys nobilis, Mylopharyngodon piceus, Ctenopharyn, odon indellus, Cirrhina molitorella, Carassius auratus, Parabramis pekinensis, Cyprinus carpio, Megalobrana terminalis* etc. The pool farming consists of artificial breeding, fry cultivation, and fish feeding.

(a) Artificial breeding

The artificial breeding depends on the condition of sexual gland of the parent fishes. They reach sexual maturation in close association with accumulated temperature of water. For example, consider *Hypophthalmichthys molitrix* in various parts of China and Vietnam. Despite substantial differences in the age of sexual maturity, this type of fish needs much the same amount of accumulated temperature of 18 000 - 20 000 ^{0}C at $t > 15$ ^{0}C. The parent fish reaching sexual maturity has its gland, after first ovulation, changing regularly with season and depending on nutrition, water temperature, isolation, current condition and dissolved oxygen, with the temperature playing a particularly dominant role among them. High water temperature favors the development and maturation of the sexual gland.

The water temperature of ovulation is fixed for a particular category in a region. For *Hypophthalmichthys molitrix, Aristichtys nobilis, Mylopharyngodon piceus, Ctenopharyn odon idellus* and *Cirrhina molitorella*, for example, the temperature is 18 ^{0}C and for *Megalobrana terminalis* and *Cyprinus carpio* it is 18 - 20 and 14 - 18 ^{0}C, respectively.

The ova develop at a certain range of temperature. *Hypophthalmichthys molitrix, Aristichtys nobilis, Mylopharyngodon piceus* and *Ctenopharyn odon idellus* (collectively four major categories of artificially bred fishes) require 18 - 31 ^{0}C for ova brooding, the appropriate range being between 22 and 28 ^{0}C. Above 31^{0}C or a sudden drop of 5 ^{0}C would cause malformation and high mortality. For *Cyprinus carpio* (*Megalobrana terminalis*) ova the temperature ranges from 20 to 25 ^{0}C (or 20 to 27 ^{0}C). Moreover, in the appropriate range the incubation period is shortened versus increased temperature.

In artificial fish breeding, the expedition of ova delivery out of parent fish should occur in a selected period, consisting of 2 to 3 fine days though there is a span between sexual maturity and ovary deterioration. This is especially important to outdoor hatching fishes like *Cyprinus carpio*.

Most of the artificially bred fisheries develop eggs in the spring, when the weather is changeable owing to the frequent clash of cold and warm masses of air, leading to abrupt rises or drops of temperature. Following a case study made for Hubei, the adverse weather index to fry breeding is the temperature dropping below 14^{0}C for *Hypophthalmichthys molitrix, Aristichtys nobilis, Mylopharyngodon piceus, Ctenopharyn odon idellus, Parabramis pekinensis* and *Megalobrana terminalis* and below 10 ^{0}C (for cold resistant *Cyprinus carpio* and *Carassius auratus*) and the adverse high temperature index is a span of two days with daily mean temperature rising above 28^{0}C. Accordingly, the optimal interval of artificially breeding fry ranges from 20 March to 30 April in Vietnam and 11 April to 20 May in China for the cold resistant fish and from the first to the second dekad of April in Vietnam and the first to the second dekad of May in China for the above categories. Based on the effects of spring water temperature on the sexual gland development of parent fishes, an expression developed by Li et al. (1985) for predicting the appropriate expedition period of *Hypophthalmichthys molitrix* in Jieshou Fry Breeding Farm of Anhui takes the form:

$$y = 24.69 - 0.413X_1 - 0.6055X_2$$

Where y denotes the first appropriate expedition time (with y = 10, the date is 10 May) and X_1 (X_2) mean temperature of April (29 April to 3 May).

It is practice common to associate the ovulation time with phenological crop observations. In the Shanghai region, for instance, barley ripening and fresh broadbean represent the optimal breeding of the four major categories of artificially bred fishes and full blossom of peach trees for *Cyprinus carpio*.

(b) Respiration Problems

Out-of-water respiration and floating is a major problem with fish breeding, particularly in cultivating parent fish and market categories. In a large-scale event, hundreds of thousand and even a million kilograms of fish may be lost. This occurs usually in a hot span of summer and autumn on account of lack of oxygen in water.

Following the study in Zhejiang by Zhang (1986), high mortality can be caused by deficit of sunshine and sharp drop of temperature, which are two categories of fish mortality. The former case takes place mainly in the periods, when wet and overcast weather often occurs, sometimes with insolation < 2 h a day. In those situations, pool fish would come out of water for respiration in the following midnight to early morning. If the daily air temperature is high and pressure is low (as shown in table 2) such a mode of respiration will be in the night, leading to high mortality. And the category of sharp drop of temperature is observed mainly in a hot season with weather marked by the maximum daily temperature greater than 32 ^{0}C accompanied by a heavy shower (>4 mm) between the afternoon and evening, causing a more than 8 ^{0}C drop and pressure decrease below 1004hPa.

Table 2. Temperature - pressure condition of fish mortality observed in the northern of Zhejiang (China Meteorological Press, 1993).

Weather conditions	Month				
	May	June	July	Aug	Sept
Daily max. temp	>18	>23	>26	>24	>22
Pres. At 20 h (hpa)	<1009	<1008	<1004	<1009	<1019

(c) Fish overwintering

Major kinds of raised fishes stop taking fodder (feed) when temperature drops around 10 ^{0}C in the transition from autumn into winter. In that case the growing creatures should be taken out, classified by size and species and put into different pools of greater depth.

The north region has a variety of wintering modes, e.g., in pools of still or running water, greenhouses, enclosed screen of reed or sorghum stalks, and chambers or closed network.

Fish are unable to survive winter mainly owing to the following:

- Anomaly of oxygen concentration in over wintering pools. Oxygen concentration in an frozen - over pool depends on the budget, i.e., the condition between daily production of the gas through photosynthesis by plankton and underwater plants, and consumption by organisms and bottom substances. The photosynthetic intensity of plankton is related to illuminance under the ice cover.

- Growth in a large water body at an unsuitable time. A suitable time should be selected for fry leaving the "nurse" pool into a large water body to grow enough before winter sets in. But their too early coming into a water body is likewise adverse. The suitable time varies from place to place; the optimal time being when the water temperature is about 10 ^{0}C and dangerous when it is below 8 ^{0}C.

- Cold water temperatures. The critical survival range is between 0.5 and 0.8 ^{0}C. At 0.2 ^{0}C fish begin dying, some losing equilibrium at 0.5 ^{0}C (one-sided upward) and dying in 12 - 24 h.

- Special weather phenomena. When a water body is unfrozen in early winter, fallen snow may be frozen by mixing with water before it melts, leading to a frozen cover that weakens rays and reduces pressure and dissolved oxygen in water by 30% as against in the case of normal freezing, giving rise to mortality.

In winter conditions, when the weather is warm, water bodies are unfrozen or only thinly iced for a short time, a condition fit for fish to pass the winter without damage. But serious attention should be paid to the problem of the overwintering of warm water fishes like *Cirrhina molitorella* and *Tilapia*, the former dying less than 7 ^{0}C and the latter less than 13 ^{0}C. In addition, water temperature in wintertime months in the south is usually above 7 - 10 ^{0}C and more, especially in warm winter years, and hence fish need fodder for development. Mortality, loss of weight and illness would occur if no feed were supplied together with intensive care.

1.1.5.2 Aquaculture in inland water bodies

Reservoirs, lakes and rivers inland are generally large sized, fluid, deep and thus rich in dissolved oxygen. For a water body, still or deep enough, great difference exists in temperature between upper and lower layers, whose water level is significantly dependent on rainfall. Inland fisheries depend closely for their growth on water temperature and other hydrological factors, among which water level determines the domain where fish travel, feed and breed so that drop of the level will cause the decrease of biological resources and hence the production.

Following Zhu (1982), the output of icefish is statistically related to the water level of the Taihu Lake, which takes the form:

$$Y = -155.90 + 96.67x.$$

in which y denotes the production (x 5 tons) and x the mean water level (m) for March to June at the Shadun Port of Wangting on the shore.

For the production of the Hongze Lake crabs, Ma (1988) indicates that the March to May precipitation (x_2) affects directly the water level which, in turn, determines the development of the young put into the lake in June, and that April - December rainfall (x_3) bears close relation to the shell - shedding and further development, whereon an equation for predicting the crab output is formulated as following:

$$Y = -1315.80 + 0.045\, x_1 + 220.1762\, \lg x_2 + 281.4421\, \lg x_3,$$

Where x_1 is amount of young crabs put in the previous year.

Fish culture in inland water bodies is seriously affected during the rainy season (especially due to the landfall of a tropical cyclone) during which time water level rises rapidly and the current runs swiftly. Fish tend to go against the current, which would result in a major loss of the fisheries if no precaution were taken against escape.

1.1.5.3 Prawn farming

The culture consists of parent prawn overwintering, and cultivation of the fry and adults.

(a) Over-wintering of parent prawns

As a rule, the wintering is carried out indoors, however, much attention should be paid to the effective control of water temperature and isolation.

Cold-water temperatures would cause high mortality of the creatures and temperatures below 6 ^{0}C (3^{0}C) can be a threat to *Penaeus orientalis* (*P. japonicus*). For *P. monodon*, they would die if living in water of below 14^{0}C for a long time (Mao, 1987). As such, the water temperature should be kept between 8 and 10 ^{0}C for *P. orientalis* overwintering and above 15 ^{0}C for *P. penicillatus, P. monodon* and *P. merguiensis* because of their adaptiveness.

Strong sunshine hinders sexual gland development of parent prawns. Therefore, light regulation (screening) facilities should be available for the pool. For *P. orientalis* overwintering, for instance, light strength should range from 50 to 200 lux. After the phase, a properly long period of insolation can be taken, depending on the condition of sexual gland.

(b) Cultivation of prawn fry

The artificial breeding is generally carried out in April (February) to June in the north (south). During breeding, the fry passes through a series of phases from sperm-ovum stage via joint-free and egg like larva and chaff-feeding fry to actual small prawn. For each of the stages, it is strongly sensitive to environmental conditions, particularly water temperature and salinity.

The larva phase requires a range of appropriate temperature for development. *P. orientalis*, for instance, needs temperature in the range of 18 to 26 ^{0}C for the development of larva embryo and within the higher temperature range favors growth, leading to a shortened period. It is therefore a common practice to keep temperature at the upper limit of the range.

Prawns are adapted to a wide range of salinity. In their earlier stages, however, they are quite sensitive to salinity. In the southern part of China, the fry breeding is during the wet season, which considerable water comes into the pools, causing changes in salinity, thus leading to distorted development and even mortality.

In earlier phases, the fry are sensitive to sunshine as well, particularly in the period of flea-form larva. For this reason, in the stages of ovum incubation and joint-free larva the breeding pools should be screened from sunshine to raise the survival rate. In and after the phase of flea-form larva, light intensity needs to be raised to above 5 000 lux in order to propagate unicellular algae as prawn feed.

(c) Raising adult prawns

The fry, when 1 cm long, are moved from the nursing pool into a larger ones for further growth until they reach about 3 cm in length and then they are put into a still larger water body. At present, the common practice in China is to raise prawns in a small-sized bay or a branch of river enclosed for extensive culture, or in a pool for semi-intensive cultivation.

The fry, especially those about 1 cm long, are liable to die when water temperature and salinity are abruptly changed such that the new water body should have temperature not less than 14 ^{0}C with the difference not greater than 8 ^{0}C as compared to the original environment, and the salinity upper (lower) deviation should be within 5% (10%).

For *P. orientalilis*, the appropriate temperature ranges are between 18 and 30^{0}C, with the optimal being around 25 ^{0}C and adverse being above 35^{0}C. The breeding area of prawns along the coast of Shandong, China has dekad mean water temperature of 25.8 ^{0}C with the highest growth in this country (Song, 1988).

In the raising of the fry into adults, the oxygen concentration in the water body should be kept above 4mm per litre. In the summer and autumn, a lack of oxygen often occurs, causing the prawns to come out of the water for respiration, in sticky breezing weather and especially in rainy windless situation after a span of fine days. For the coastal area of eastern Shandong, for instance, prawns would tend to come out of water for respiration in the night until sunrise and even die because of the low concentration of 2.54 mm/lit, on average, if the pressure was less than 1 000 hPa at 200 BT.

Torrential rain in summer adversely impacts growth since it reduces the salinity of the water suddenly, thus affecting the physiological process. Moreover, freshwater from the rainfall is at the surface, hindering gas exchange of the lower layers of the seawater with air. On a wind free day the freshwater layer can persist for a long period of time, deteriorating the quality of lower level water so as to kill the prawns in some cases. Hence, after a heavy rain part of the surface water should be discharged as soon as possible, and the water should be mixed if stratification was found.

1.1.5.4 Freshwater pearl - mussel farming

Freshwater pearls are extracted from the related mussels. Grown in China, Japan, Vietnam and other countries in Asia are the species *Hyriopsis cumingii* and *Unio margaritiferus* for pearls. The artificial culture consists of mussel propagating and cultivation of the young and adults for pearls.

(a) Artificial breeding of pearl - mussels

The development of freshwater mussels depends heavily on temperature. Studies show that a fertilized ovum reaches an adult of sexual maturity with accumulated temperature of 28 000 ^{0}C at a temperature more than 11 ^{0}C at the 0.5 m deep water. Then the mussel can be used as a parent for artificial reproduction. *Hyriopsis cumingii* matures sexually by beginning to release ova for fertilization at water temperatures of 16 ^{0}C and it is discharged as a larva at 18 ^{0}C.

The artificial breeding of freshwater mussels needs special condition. Following Fang (1985), the development of the young are possible in the water temperature range of 18 - 35 ^{0}C, with the optimal being 22 to 26 ^{0}C and adverse being less than 18 ^{0}C and more than 35 ^{0}C to the survival rate of the larva.

The parasitic duration (usually 7 - 15 days) of fertilized ovum to a young mussel on a fish depends on accumulated temperature of the water. When temperature sums reaches 219.0 ^{0}C at $t > 18$ ^{0}C, the young start to leave the host. Based on this index, an appropriate period can be fixed for gathering young mussels.

(b) Cultivation of freshwater young mussels

The cultivation refers to the process by which young mussels are developed into those greater than 10 cm in length. Caution should be taken against excessively high water temperatures and the hazard of luxuriant bottom moss that may kill the young. This occurs when they are in 10 to 15 cm of deep water and sunlight can easily pass through to raise the temperature substantially and thus to promote a rapid moss growth. For this reason, the pool should be properly screened. On the other hand, corresponding measures are to be taken in winter lest the young should die of cold.

(c) Cultivation of pearl producing mussels

When freshwater mussels are 12 -16 cm long, "embryo" implanting is carried out for pearls, after which they are called pearl-raising mussels. As a rule, brilliant pearls are collected in two years (including the summer of the third year).

The implanting can be performed with mussels that grow in an environment of water 0.5 m deep with temperature sums of 17 000 ^{0}C at temperatures greater than 11 ^{0}C.

The growth of the mussels and the secretion of the pearl formation liquid requires a definite environmental condition. The mussels should be moved upward and downward according to water temperature and sunshine regimes to eliminate large excessively high and low temperatures, icing, and torrential rain and to increase the survival rate. output, and improve the quality of pearls. The height for suspending mussels is, generally, raised (reduced) in spring and autumn (summer and winter). Besides, caution should be experienced against gales in excess of force 8 which would damage the facilities.

1.1.5.5 Climate and Fish Catch

The central problem is to fix the time and place for the operation.

(a) Catching of natural fry

The main areas of natural fry are the river systems that serves as a region for providing the four major categories of artificially bred fishes from the middle or last dekad of April to early July while the latter offers fry of *Cirrhina molitorella* in the main and of *Ctenopharyn odon idellus* over the span from the mid-April to the end of August.

There are certain periods of the year when fry can appear in vast quantities. To correctly predict these periods is very important since a great deal of fry can be caught in time to be put into lakes and reservoirs for culture, and then are led directly into coastal fisheries from the rivers. But no scientific methods have as yet been reported concerning the prediction of fry appearing in clusters.

In Hubei province, a common proverb states that the appearance occurs around day 120 from the first snow after the winter solstice and around day 90 from the first snow after the beginning of spring (first solar term), regardless of winter snowfall (China Meteorological Press, 1993).

In the Wuhan region, there is saying that "rainstorms (dark cloud) in the southwestern portion of the sky foreshadows fry catching on day 8". In Guangxi province, there is a proverb that states that "the fry catching period comes after a 3-day rainfall from late spring to early autumn”. In Guangdong province, fishermen have the experience that the fry catching span will usually come in 7 - 10 days if lightning and heavy rain occur in the upper basin of the Xijiang River and to the northwest.

The weather condition has effect on the operation. An abrupt drop of temperature exerts an influence on the egg laying of the parent fish and the subsequent hatching. In chilly weather only a small amount of fry is caught because they tend to go into deeper water. With a stronger southern (northern) wind fewer fry are found on the northern (southern) side of the river. If the wind is too strong, the operation should be stopped. Fry appear in larger quantities on a fine day and the daytime hours than on a wet day and in the night, respectively.

(b) Harvesting artificially-raised fish

The harvesting of artifically-raised is usually done from late autumn to early winter and the output depends on the start of catching time. According to Zhang (1986), the optimal time (water temperature index) of catching in Jiashan, Zhejiang is around 15 ^{0}C for *Aristichtys nobilis* and *Hypophthalmichthys molitrix* and 10 ^{0}C for *Mylopharyngodon piceus* and *Ctenopharyn odon idellus*.

The fishing in summer and autumn should be carried out at dawn or early in the morning of a fine cool day when the daily temperature is high enough to suppress the fish activity, which makes them unable to get together for long and to stand the disturbance. In addition, after catching, the pool should be replenished with water lest the remaining come out of water for respiration and even die due to lack of dissolved oxygen.

(c) Harvesting artificially-raised prawns

In later growth stages of prawn development, they grow rapidly so that the harvesting time should be selected by considering such factors as the condition of growth, water temperature, food supply and tidal pattern. *Penaeus orientalis* is to be taken out of water before the temperature drops to 13 ^{0}C and *Penaeus penicillatus* before it drops to 15 ^{0}C.

(d) Open-sea fishing

Most of the species of sea fishes are migratory but have different patterns. It is thus of vital importance to the catching, particularly in open-sea operation to understand the time, routes, and causes of the migration.

In Chinese waters, *Trichiurus lepturus* is divided by the regional oceans: South China Sea, East China Sea and Huanghai - Bohai Seas. In these ocean regions their distributions and migratory courses are distinct and related to each other. The East China Sea group migrates towards the north from March, producing eggs and looking for feed. Beginning from October when cold air comes over the waters which causes a drop of the water temperature, the fish begin to migrate back for food and gather in the mixed waters around the Chengshan Islands fishery and then will go farther south for overwintering. During this period, cold air outbreaks become frequent with strong winds at an interval of 3 to 5 days causing a drop of water temperature and subsequently an increase of fish volume. At this time, if there high salinity water outside the fishery and the volume is large, then the gathering enters its climax. After that the group moves south, arriving in the Dongtou fishery of southern Zhejiang in early December, then in the Niushan Fishery of Fujing, and then in the waters of southern Fujian between early January and late February. Finally a small part reaches the offshore waters of Guangdong.

For *Penaeus orientalis* found in the Huanghai and Bohai Seas they have different migratory routes for wintering and reproduction. According to Ding [12], the time for the prawns to leave the Bohai Sea across the Chengshantou strait is related to the July - September mean air temperature and the strong winds due to the cold air outbreaks. The migration is late if the mean temperature is high. As a rule, it occurs on the same or next day of the start of the strong wind.

(e) Climatic conditions in relation to the Transportation of Aquatic Products

In this section the focus is on the transportation of live fish, including fry, eggs, parent and edible fish. The transportation is separated in to two broad categories: close and open. The limiting factors many, but the main ones are water temperature and dissolved oxygen.

Transporting aquatic products require an appropriate range of water temperature. Specifically, 5 to15 ^{0}C is necessary for the four major categories of artificially bred fishes, 5 to 10 ^{0}C for *Cyprinus carpio* and 18 to 20 ^{0}C for *Tilapia*. In the southern areas, the transport of the adult fish is carried out between autumn and winter when adult fishes are caught while in the north it is performed in spring and autumn when temperatures are suitable.

Oxygen consumption of fish is associated with the species and size as well as water temperature. The density of transported fish is a key link for the survival rate and is based on water temperature, dissolved oxygen, fish species and size, transporting methods, vehicle, and distance traveled. With higher temperature the density should be lowered and hence lower efficiency.

During transportation, especially in hot weather, live fish often die because of considerable oxygen consumed on the decomposition of mucus from the skin, fish dung, with much heat released, especially in the case of *Monopterus albus*.

When the conveyance is performed in a closed container in which CO_2 discharged from respiration is accumulated, sometimes the increased concentration suppresses metabolism and even causes the death. Studies show that for concentration in excess of 100mg per litre, the fish will become numb and with a doubling they will die.

Table 3. Density of different - sized fish transported in water of different temperature

Size (cm)	Temperature (^{0}C)	Density (num./lit)	Period (d)
~2.2	25 - 30	75 - 90	1 - 2
3.3	25 - 30	65 - 70	1 - 2
5.0	25 - 30	45 - 50	1 - 2
8.2 - 10	10 - 15	25 - 30	1 - 2
13.2	10 - 15	10 - 15	1 - 2

Fish species with the ability to respire through the skin to a certain degree can be transported in a water free damp container. These species include: *Anguilia japonica*, *Silurus asotus*, M*onopterus albus*, *Misgarnus anguillicaudatus*, *Cyprinus carpio*, and *Carassius auratus*. In doing so, focus should be on the skin moisture. Therefore, extreme temperatures and strong winds have considerable effects in the process. The technique should not be applied at temperatures greater than 15 ^{0}C with less than 10 ^{0}C preferable.

(f) Climate and Preserving Aquatic Products

The preserving and processing are unseparated and closely related to climatic conditions. It is of commercial significance to process a bulk of fresh aquatic products in terms of a preservation technique in a short time before they spoil. Temperature is the leading factor responsible for the speed of deterioration and decay. For freshwater fish, for instance, the optimal temperature for the fish enzyme activity and microbe breeding is 25 to 30 ^{0}C. For this reason, cold temperature preservation is the principal method in current use.

Preservation without cryogenerators is widely adopted, therefore the duration is dependent on the temperature of the fish itself, as shown in Table 4. The efficiency of ice preservation is directly associated with air temperature. The higher the temperature, the more ice used and the lower the efficiency.

Table 4. Fish temperature and fresh preservation period

Fish temperature (^0C)	Preservation length (days)	Fish temperature (^0C)	Preservation length (days)
10	1.5	7	2 - 3
5	3 - 5	3	5 - 6
0.5	6 - 8	0	8 - 10
-0.25	11 - 12		

1.1.6 Processing of Aquatic Products

Meteorological factors have an influence on the processing and storage of treated aquatic products. The drying of aquatic products depends on solar radiation and wind and rainy weather is detrimental to the storage and ultimate consumption of the products. In the south, for example, *Laminaria japonica* is normally harvested from the mid-April to mid-June during which the wet season arrives, that often causes the decay of the products being processed. In drying aquatics, excessive sunshine and high temperatures are also undesirable. For fish, particularly fatty species, when treated in the summer, for instance, should be moved into shade during in midday lest the fat should be oxygenated considerably and producing unpleasant odors. In producing pickled products, high temperature will increase the decomposition of the soluble protein in the brine causing the products to soften and give off unpleasant odors.

The storage depends on climatic conditions as well. Dried pickled aquatic products, for instance, will be moistened and deteriorated in an environment of high humidity, and high temperature and humidity will allow bacteria to multiply, producing red pigment that will deteriorates the products. The acidity of distiller's grains in which aquatics are pickled may change substantially at high temperatures by reducing the content of alcohol, reducing the ability to inhibit bacterium growth and resulting in deterioration and decay.

1.1.7 Climatic Problems with Aquaculture and Countermeasures

Climatic conditions in many countries are very favorable for aquaculture. But the difference in climate from region to region and from the annual as well as seasonal variations can have adverse effects on successful aquaculture.

(a) Overwintering difficulties with northern fisheries

Northeastern and northwestern and the northern part of North China experience severe winters with thick ice over water bodies, leading to a varying mortality of overwintering fish in medium to small sized reservoirs and ponds, the exception being the rare occurrence in very large reservoirs, rivers and deep lakes during extremely cold winters. It is a major climatic issue for these regions in aiding fish to survive the cold winters. On the other hand, there exists the likelihood of winter mortality of warm water fish in the south, where winter is usually warmer than in the north.

(b) Mortality of fish in pools and ponds in hot summers

In the mid and lower basins of the Changjiang River and coastal plains of southeastern China, summer temperatures are often in excess of 30 ^0C, producing conditions at the edge of the appropriate range of fisheries, thus inhibiting their normal growth to some degree. The high water temperature causes fish and shrimp to increase their respiration and consume more dissolved oxygen, so that they have to come to surface for respiration and even die because of lack of the oxygen.

(c) Short period of fish growth in the Yunnan - Guizhou Plateau

In this period, fish have a shorter period for normal growth on account of the high altitude and lower temperature in summer, thus resulting in lower output.

(d) Large portion of annual precipitation in a relatively shorter period responsible for the unstable development

In some parts of the country, a high percentage of the rainfall is received for a short period of time, leading to the water level of reservoirs experiencing cycles of substantial increases and decreases. In hilly land, there is a large problem of the distribution of water resources between crops and fish in dry season, with result that aquaculture is affected and unable to be maintained on a stable basis, especially in northeastern, northwestern, and northern China. Likewise, between the end of the dry season and start of wet season, rice transplanting is done in Yunnan, Guizhou, and Sichuan provinces and a large volume of water is needed for this farming activity, leaving hill ponds and reservoirs with little or no water. The water problem also exists to some extent in the catchment of the Changjiang river in central and eastern China and hilly areas to the south where summer drought is usually quite serious.

(e) Countermeasures

In dealing with the above issues of aquaculture, the following aspects can be considered:

- Based on the characteristic environment consisting of the prevailing weather, climate and water condition for a given area, the right species and varieties are raised with reasonable density and proportion. Wherever possible, multilevel and mixed modes are practiced so to make full use of favorable regional climate and water resources. Caution should be taken when weather and climate change. Water bodies should have the necessary depth and feeding in accordance with the prevailing weather conditions. Of course, it is important to minimize the effects of adverse weather and climate, e.g., cold winters, hot summers and excessive rainfall in warm season. Extra oxygen should be supplied for fish pools that would otherwise suffer from a lack of oxygen, before tropical cyclones, torrential rain and thunderstorms arrive and bring the need water supplies.

- The water level of natural water bodies should be regulated for the reproduction and protection of fisheries due to excessive and deficit rainfall in wet and dry seasons, respectively. The water level of rivers in northeastern and northern China changes too much to undertake successful aquaculture, but this can be performed in reservoirs pools and lakes. In Yunnan, Guizhou, and Sichuan provinces where water is scarce for aquaculture during the rice-transplanting period, it can be done in paddy fields, whereby the ecological condition of the fields can be improved and utilized.

- The ecological condition of water bodies should be ameliorated by modifying the structure of breeding pools and ponds. For example, an east-west facing pool has a longer period of sunshine than oriented otherwise; the quantity of dissolved oxygen is larger in a larger pool; the shrimp breeding pool should have ditches in the bottom of the central part of the pool to avoid the hot summer weather. In northern China, where fry resources are limited, an indoor pool should be built using geothermal resources and waste heat from power stations, whereby the ability to raise fry is increased to meet the needs of aquaculture development.

- Meteorological studies should be conducted on aquaculture to understand the ecological condition of growth and propagation of various fisheries. It is necessary to provide meteorological services in order to gain greater economic, social and ecological benefits.

1.2 SOME ORIENTATION IN THE DEVELOPMENT OF HYDROMETEOROLOGICAL AND ENVIRONMENTAL INFORMATION TO SERVE AQUACULTURAL PRODUCTION

1.2.1 Requirements of using hydrometeorological and environmental information to serve aquaculture

In practicing aquaculture production, the following hydrometeorological and environmental information are needed:

In fresh water regions:

- Air and water temperatures
- Water level and speed of stream flows in rivers and lakes and other water bodies,
- Water quality and level of toxic substances in different water bodies,
- Rainfall and numbers of rainy days
- Air humidity
- Air pressure
- Wind speed and direction at water bodies,
- Sunshine (isolation) duration, number of overcast and clear days

In brackish water and coastal regions:

- Air and water temperatures
- Water level and speed of stream flows
- Water quality and level of toxic substances in different water bodies,
- pH and salinity,
- Rainfall and numbers of rainy days
- Air humidity
- Air pressure
- Wind speed and direction at water bodies,
- Sunshine (isolation) duration, number of overcast and clear days

1.2.2 To strengthen the capability in providing hydrometeorological and environmental information for aquaculture production

As compared to the requirements in using hydrometeorological and environmental information for aquaculture production, it is clear that the capability to collect this information in hydrometeorological and environmental networks in many countries is very weak to meet the demands of this important activity. Some of the major reasons of this are:

- The networks for observation and collection of hydrometeorological and environmental information are very rare in many countries, especially in developing countries,

- The networks and equipment for observation and measurements, as well as analysis of water quality are also very rare because this equipment is very expensive and sensors are hard to maintain in to brackish and salinity water bodies.

- The observation and measurements of hydrometeorological and environmental elements often carried out mainly in scientific investigations or surveys. In some countries the regular networks for those observation and measurements are not established.

In order to strengthen the capability in providing hydrometeorological and environmental information for aquaculture production, the following recommendations are given:

To develop the hydrometeorological and environmental networks of observations and measurements:

In fresh water regions:

- Air and water temperatures
- Water level and speed of current in rivers and lakes and other water bodies,
- Water quality and level of toxic substances in different water bodies,
- Content of dissolved oxygen in water bodies,
- Rainfall and numbers of rainy days
- Air humidity
- Air pressure
- Wind speed and direction at water bodies,
- Sunshine (insolation) duration, number of overcast and clear days

In brackish water and coastal regions:

- Air and water temperatures
- Water level and speed of currents in water bodies
- Content of dissolved oxygen in water bodies,
- Water quality and toxic substances in different water bodies,
- pH and salinity,
- Rainfall and numbers of rainy days
- Air humidity
- Air pressure
- Wind speed and direction at water bodies,
- Sunshine (insolation) duration, number of overcast and clear days

For both regions:

To improve the equipment for measurement and analysis environmental elements, especially for fresh and brackish water regions, as well as coastal regions;

To organize workshops and training courses to exchange and disseminate methodologies on observations and measurements of environmental elements for fresh and salt water aquaculture;

To add a section or paragraph on observations and analysis of hydrometeorological and environmental elements serving aquaculture production in the new Guide to Agricultural Meteorological Practices;

To increase the development of hydrometeorological and environmental research activities in serving aquaculture production.

It is obvious that aquacultural production can bring great economic benefits and is developing very fast in many countries over the world, especially in those countries where there are large area of water bodies and coastal regions. Nevertheless, due to different reasons, up to now, hydrometeorological and environmental research activities in serving aquaculture production have not been and are not corresponding with the demand of this important branch of economy.

Therefore, along with strengthening the capabilities in the provision of hydrometeorological and environmental information serving aquaculture, the enhancement of research activities in the fields of applying this information is needed as soon as possible.

Research activities should be concentrated into the following major aspects for fresh, and brackish water as well as coastal water regions:

1) To study the relationships between growth, development and productivity of fisheries and hydrometeorological and environmental conditions in those regions.

2) To study the hydrometeorological and environmental factors that cause disease in aquaculture farms.

3) To study and develop rational hydrometeorological and environmental networks.

4) To study the combination of weather conditions causing stress for growth and development as well as causing malformation and high mortality of fisheries.

5) To determine the regions with hydrometeorlogical and environmental conditions suitable for artificial fishery cultivation, fertilization and hybridization.

6) To study methods for hydrometeorological and environmental forecasts for artificial fishery cultivation, fertilization and hybridization.

7) To study methods for forecasting the environmental elements in different water bodies.

8) To study methods for forecasting diseases in aquaculture.

9) To study farming systems combined with aquaculture in order to increase economic benefits in exploitation and environmental protection.

1.2.3 Some activities in developing the network of observation and measurement of hydrometeorological - environmental elements for aquaculture production in Vietnam

The role of aquaculture in Vietnam

In Vietnam, the demand for aquatic products is steadily increasing. Up to now, aquaculture supplies about 12 kg fish/person, among this 30 - 50% are from freshwater fisheries. Aquatic products are exported to more 46 countries and regions over the world.

The economic benefits of aquaculture are very high and higher than agriculture, livestock (1 kg of shrimps is equal to 50 kg of rice). Aquatic cultivation creates many jobs for farmers. It is very important for the country where about 80% population is farmers.

For the Ministry of Fishery of Vietnam, observation, measurement and analysis of environmental elements of water in aquatic zones is very important, especially when aquatic production plays a significant role in the economic development of country. The establishment of a network for monitoring and early warning for water quality can make a considerable contribution in determining the yield and quality of aquatic products in Vietnam as well as reducing the risk in aquatic cultivation by providing early warnings environmental factors affecting aquatic production.

The purpose of observation and analysis of water environments in the short and medium time range serves research, preservation and development of aquatic resources and aquatic planning.

In Vietnam, updated forecast information on hydrometeorological conditions and quality of water environments is very important for aquatic production, including its cultivation as well as exploitation of aquatic resources. Based on this information, the farmers will be able to avoid risks due to weather and environments. In the future, this information will be used in development planning, zoning for aquatic cultivation and harvesting fish.

1.2.4 Project on the establishment of a network for observation, measurement and warning for water environments serving aquaculture in Vietnam

Goal and objectives of the project:

(a) To set up a network for observation, measurement of daily, monthly, annual elements of water environments in regions of aquatic production in order to provide early warnings to farmers in dealing with the risks of aquatic cultivation,

(b) To develop a database on behaviors of water quality for aquatic cultivation as a base for determining strategies of sustainable aquacultural development in those regions,

(c) To undertake cooperation and exchanges of information with concerned agencies in the field of aquatic cultivation, as well as the study and suggestion of development directions for aquatic resources and selection of avoidance measures when diseases occur.

Structure of the network

The network will consist of the following units:

1) Institute of Aquatic science (IAC)
2) Central laboratory at the Institute of Aquatic science
3) Regional centres,
4) Regional laboratories,
5) Stations for hydrometeorological and water environmental observation and measurement in regions.
6) Centre of Database at the IAC and regional centres,

The flowchart of the network shown in Figure 1.

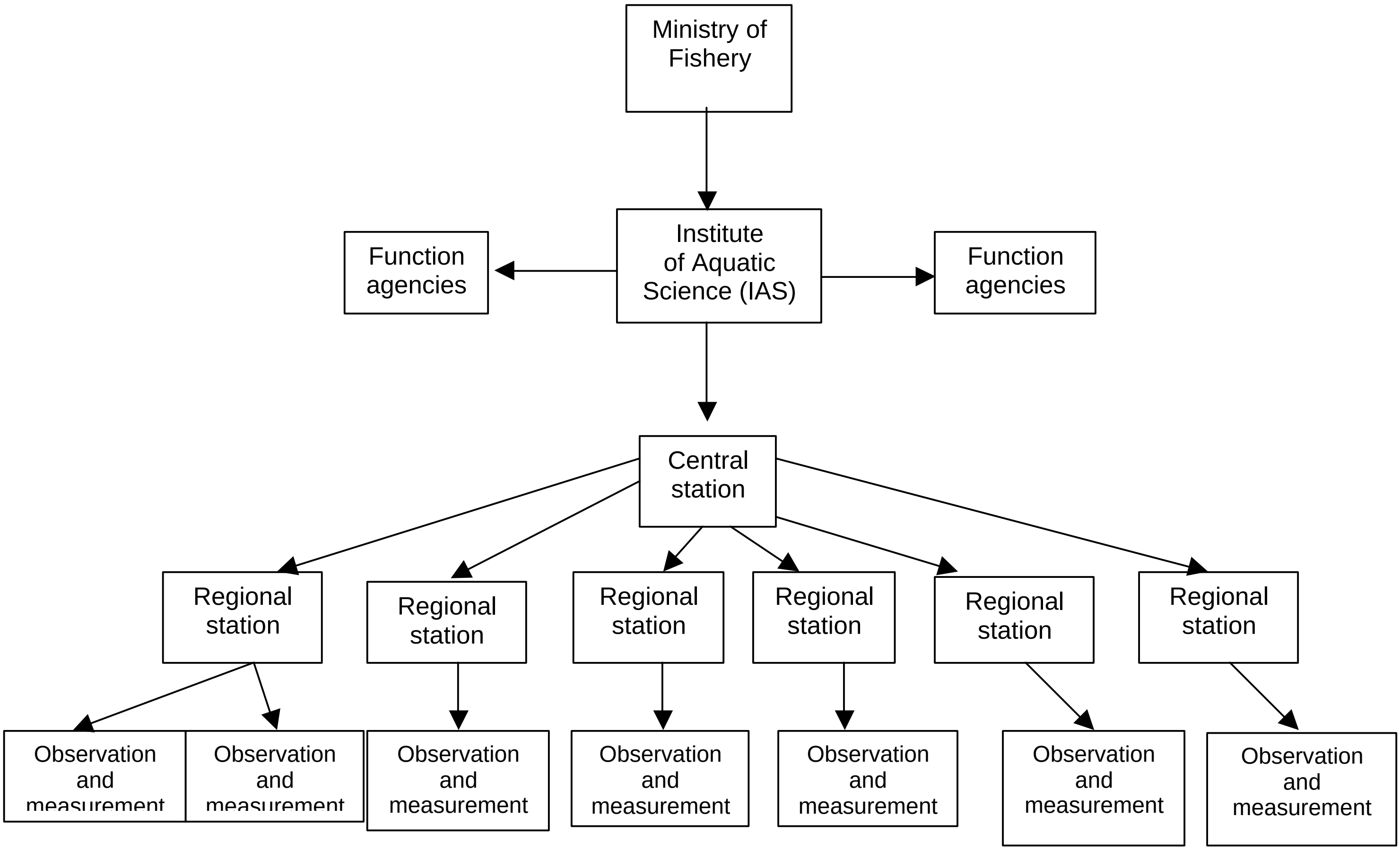

Figure 1. Flowchart of structure of network for hydrometeorological - environmental observation and measurements

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1.4 FURTHER READING

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Chapter 2

IMPACT OF THE USE OF ENVIRONMENTAL DATA ON FISHERIES AND AQUACULTURE IN NEW ZEALAND

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2.1 INTRODUCTION

This report addresses the terms and references proposed under Resolution 14 of CAgM-XI.

a. To survey and summarise existing uses of meteorological and climatological data on fisheries and aquaculture.

b. To describe, using case studies from Member countries, the impacts of such information.

c. To suggest ways and means to improve further agrometeorological information for applications in fisheries and aquaculture.

The scope of this report has been expanded to include reference to other environmental data like sea surface height (SSH), chlorophyll-a, and moon cycle, which are neither meteorological nor climatological, but have undoubted potential in fisheries science. Like the climatological category sea surface temperature (SST), SSH and chlorophyll-a are available as satellite remote sensing data.

2.2 THE NEW ZEALAND ENVIRONMENT

New Zealand is an archipelago in the southwest Pacific with an exclusive economic zone that ranges from 26 °S to 56 °S, 160 °E to 172 °W (Figure 1). New Zealand's aquatic environment is diverse, from shallow estuarine to deep-water oceanic in the marine environment, and numerous freshwater and brackish habitats in lakes, streams, and rivers.

Within this diversity a wide variety of fisheries operate. Commercial fisheries are mainly marine, but there are also targets in the freshwater environment, including eels (*Anguilla australis*, *A. dieffenbachii*, *A. reinhardtii*) and mullet (*Mugil cephalus*). Marine commercial fisheries utilise a wide range of gear types, including pots, set-net, purse-seine, bottom and midwater trawl, and surface and bottom longline. They target a range of fishes including inshore pelagic species like jack mackerel (*Trachurus declivis*, *T. symmetricus murphyi*, and *T. novaezelandiae*) and blue mackerel (*Scomber australasicus*) many inshore demersal species like blue cod (*Parapercis colias*), groper (*Polyprion oxygeneios*, *P. americanus*), and John dory (*Zeus faber*), highly migratory pelagic species like southern bluefin tuna (*Thunnus maccoyii*), middle depths species like hoki (*Macruronus novaezelandiae*) and hake (*Merluccius australis*), and deepwater species like orange roughy (*Hoplostethus atlanticus*) and oreo (*Alloscyttus niger*, *Neocyttus rhomboidalis*, *Pseudocyttus maculatus*), as well as mollusks like paua (*Haliotis iris*) and crustacea like scampi (*Metanephrops challengeri*).

Recreational fisheries occur in freshwater for brown (*Salmo trutta trutta*) and rainbow trout (*Oncorhynchus mykiss*), and in the marine environment for a range of gamefish species like marlins (striped marlin *Tetrapturus audax*, blue marlin *Makaira mazara*, black marlin *Makaira indica*), sharks (mako shark *Isurus oxyrinchus*, blue shark *Prionace glauca*), and tuna (yellowfin tuna *Thunnus albacares*, albacore *T. alalunga*), and other popular species like snapper (*Pagrus auratus*), kahawai (*Arripis trutta*), and blue cod (*Parapercis colias*). Within this variety there is the need for a number of types of environmental information, for predicting the availability and distribution of fish and the efficacy of undertaking fishing activity, and for determining factors important in recruitment and growth variability.

Aquacultural development has progressed markedly in New Zealand over the last ten to twenty years and is now well established. Three species, mussels (*Perna canaliculus*), salmon (*Oncorhynchus tshawytscha*), and oysters (*Crassostrea gigas*), are successfully farmed, and the enhancement of wild scallop (*Pecten novaezelandiae*) stocks has been undertaken successfully on a relatively large scale. Rearing of animals in captivity has been developed, with abalone (*Haliotis iris*, *H. australis*) farming now well established, and research on the captive rearing of lobster (*Jasus edwardsii*), large-bellied seahorse (*Hippocampus abdominalis*), and kingfish (*Seriola lalandi*) well advanced.

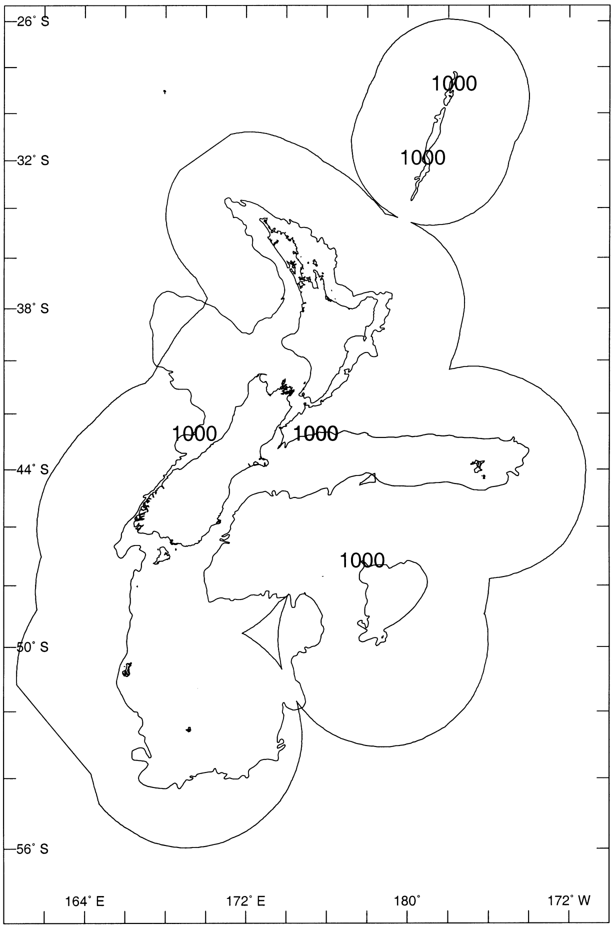

Figure 1. New Zealand and its exclusive economic zone with 1000 m bathymetric contour.

Also within this industry is the need for a variety of environmental information, once again for predicting the availability and distribution of wild fish and the efficacy of undertaking collection of wild animals, and also for predicting variations in spawning season and extremes of environmental variability and their effects on animals held in captivity.

Assessments of wild fish stocks and their management is a statutory requirement of the Ministry of Fisheries for all species in the quota management system (QMS). Currently, seventy species are included, with several being added each year; for example, ten species will be introduced on October 1, 2002 (Annala et al. 2002). Stock assessments vary from complex age-structured models with accompanying yield estimates, to simple catch monitoring using fish-size frequencies. Catch per unit effort approaches are common, and standardisation techniques using multiple regression have been developed that incorporate environmental predictors where possible.

Collection of environmental data has been in place since the nineteenth century, although datasets in the early years are seldom continuous and mostly limited to air temperature and rainfall. Nevertheless, these data have been used in fisheries analyses and work has shown that air temperature can be a reliable proxy for sea surface temperature (Gilbert & Taylor 2001). More recently the types of environmental data available have increased, particularly with the development of satellite remote-sensing strategies, although the length of time series is usually too short to match the temporal range of available fisheries data. In some cases this can be overcome by combining data from different sources. Combined shipboard and satellite data provide global SST data that extend back more than 50 years, which have proved useful with some species. Ultimately the widespread potential application of these data indicates a high degree of improvement in all the areas mentioned above. As datasets expand, their importance in influencing variation in fish and fisheries will be discovered, and the predictive power of environmental information utilised.

2.3 DATA

A number of data types are important in the present context, and some can be considered within the context of complex systems that comprise a number of inter-related elements. For example, in coastal South America, ENSO (El Niño-Southern Oscillation) events are known to affect seasonal wind strength and direction, depth of the thermocline, and consequently the nutrient and oxygen loading of water in coastal upwellings, which in turn impacts on fish species and the fisheries for them (Philander 1991, Bakun 1996). ENSO events are also important in New Zealand, but the mechanisms by which fisheries are impacted are not well understood. By contrast environmental impact on fish species appears, in some cases, to be through action of a single factor. In particular, sea surface temperature is of wide ranging importance in developing predictive models for marine species.

2.3.1 The Meteorological/Climatological Database

A variety of meteorological data are collected by New Zealand agencies and stored in a database at the National Institute of Water and Atmospheric Research (NIWA) (Penney 1997). These include data recorded from land-based and ship-board weather stations. Some are more extensive than others, some are too patchy to provide consistent time series, and some, like “earth temperature”, are unlikely to be useful in a fisheries context. The full range of data are summarised in Table 1.

Table 1. Meteorological data available from the climate database administered by the National Institute of Water and Atmospheric Research (Penney 1997).

Data Type	Description
Annual statistics	Annual totals, means, and extremes
Cloud layer	Amount, type, height for a cloud layer
Cloud system	Summary of low, middle, and high cloud
Daily statistics	Daily means and extremes
Earth temperature	Temperatures recorded at various depths in earth
Evaporation	Evaporation from raised (and sunken) pans
Ice	Ice accretion on ship, sea ice observed
Lightning	Counts of lightning bolts
Maximum gust	Direction and speed of highest wind gust
Maximum, minimum temperature	Maximum, minimum, grass-minimum extreme temperatures
Monthly statistics	Monthly totals, means, extremes
Normalised annual statistics	Normalised annual statistics for 30-yr period
Normalised monthly statistics	Normalised monthly statistics for 30-yr period
Pressure	Mean sea level and station-level pressure and change

Data Type	Description
Radiation	Global, diffuse, direct radiation
Rain	Precipitation amount, state-of-ground and estimated water balance
Rain rate	Digitised duration/amounts at constant rate
Screen observations	Dry, wet, dew temps and RH in screen
Sea observations	Sea-temp, waves, swells, ships track
Ship observations	Wind, temp, pressure reported by a ship
Ship weather	Clouds, vis, weather reported by a ship
Snow	Depth of fresh and total snow
Soil moisture	Moisture in soil as percentage by volume
Sunshine	Duration of bright sunshine
Surface wind	Direction and speed of wind near surface
Ten minute statistics	Ten minute values and statistics for various elements
UV radiation	Data for UV radiation
Upper air	Dry/dew temp, direction/speed at given pressure/height
Weather	Visibility
Weather phenomena	Gale, snow, hail, lightning, thunder, fog, dew

2.3.2 Freshwater Level/Flow Data

River level/flow and lake level data are available from two main sources. NIWA administers a system of 304 recording stations throughout New Zealand, whose data are recorded on the NIWA hydrometric database. Also available from this database are historical data from a further 641 stations that are no longer operational. Regional authorities throughout the country administer additional recording stations of a number similar to NIWA's operational stations.

2.3.3 Satellite Remote Sensing Data

A variety of data are available from this source, including the environmental data referred to above that are not of a meteorological/climatological nature (Table 2). Of interest to fisheries and aquaculture are sea surface temperature, sea surface height, chlorophyll-a, and sediments and Gelbstoff. Data are available in a range of resolutions from 5 ° x 5 ° and 1 ° x 1 ° summaries over differing time frames, to high resolution data available directly from satellites in real time. In addition to providing mean values for areas at a given resolution, high resolution data can be used to derive positions and the extent of features like thermal fronts, seamounts, and sea currents.

Table 2. Satellite remote sensing data

Environmental factor	Features observed or derived
Sea surface temperature	Thermal fronts, sea currents
Sea surface height	Position of sub-surface features (e.g., seamounts), sea current anomalies
Chlorophyll-a	Areas of productivity, sea currents
Sediments & Gelbstoff	Areas of particular habitat, water clarity

2.4 COMPLEX ENVIRONMENTAL SYSTEMS

2.4.1 Synoptic data types

Two map classifications of synoptic weather (low-level air flow) types based on circulation patterns derived from gridded atmospheric data (e.g. mean surface level pressure, MSLP) were developed for New Zealand by Kidson (1997) (Figure 2). These can be used to specify departures in daily and monthly climatic elements and expressed as time series throughout a period of interest.

2.4.2 Southern Oscillation Index (SOI)

The SOI provides a quantified measure of the atmospheric component of the El Niño-La Niña cycle. It is calculated as the difference in MSLP between Darwin and Tahiti, which is a good indicator of the exchange of atmospheric mass between the eastern and western tropical Pacific.

2.4.3 Pacific Decadal Oscillation index (PDO)

Early indications of the existence and effects of the PDO (Mantua et al. 1997) came from records of salmon catches on stretches of the west coast of North America. Out of phase alternations in catch levels between the Alaskan coast and the Columbia river region appear to be related to Pacific basin-wide oscillations in sea surface temperature, near surface winds and other variables, that operate on a 20–30 year time scale.

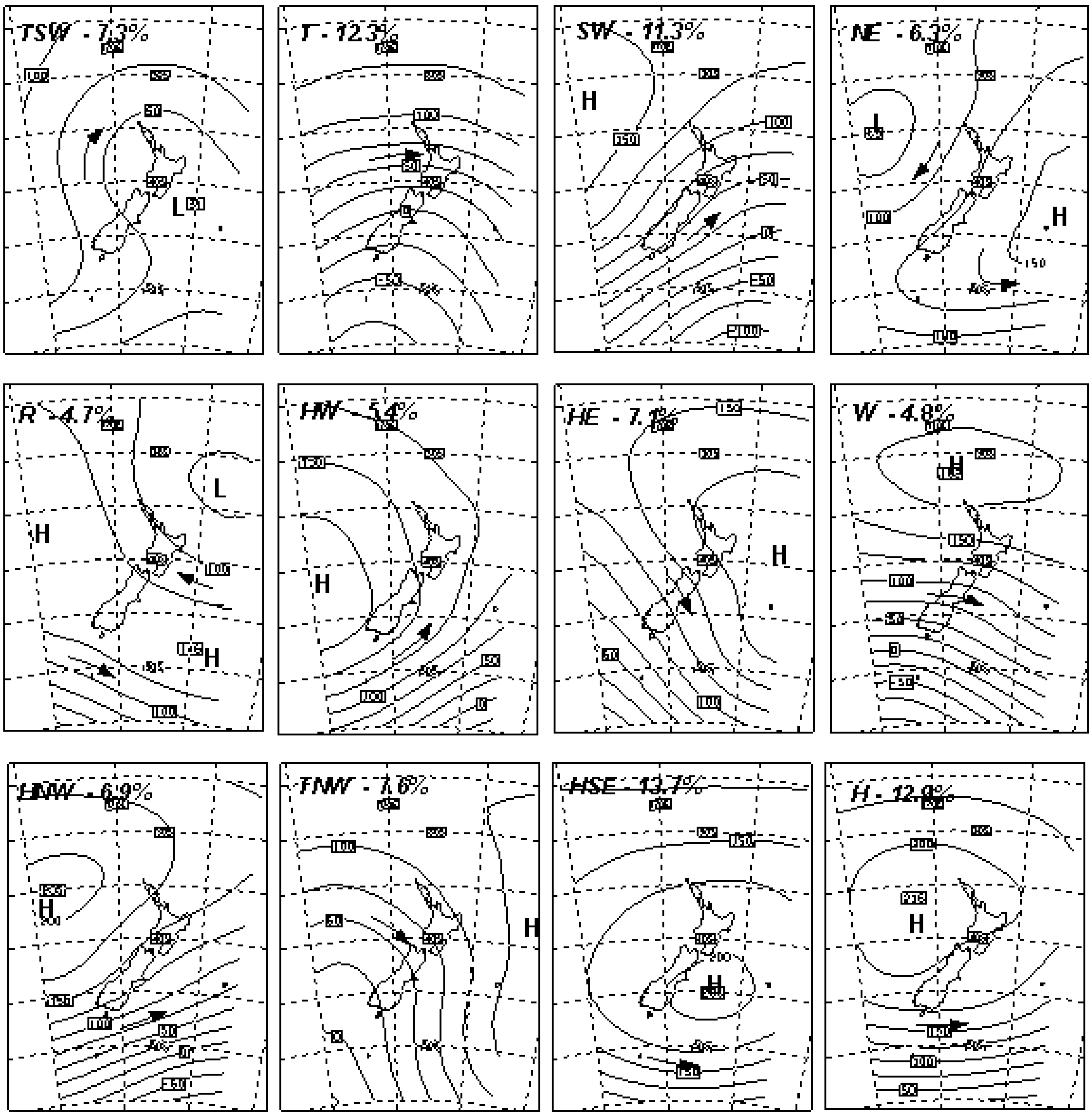

Figure 2. An example of synoptic weather types used in studies discussed in the text.

2.4.4 Other indices

Trenberth (1976) developed a set of MSLP indices for the New Zealand region, based on long records (up to a century or more) from land stations. The indices are proxies for mean westerly (zonal) and southerly (meridional) wind strengths over different parts of the New Zealand/Tasman Sea region. They have been used extensively to characterize variations in New Zealand climate.

2.5. USES OF THE DATA

2.5.1 Monitoring Access to a Fishery

Access to a fishery is perhaps the most widespread impact of environmental factors in the fishery context. Two formats of related information are important. The first is where a fisherperson is interested in predicting the likelihood of being able to undertake a period of fishing or, in the case of aquaculture, a period of animal capture, and consults weather forecasts for summarised information or weather maps for personal interpretation. In New Zealand this information is widely and readily available from most media sources and through direct, paid consultation with the National Meteorological Service (the Met Service).

The second is where existing time series of explanatory variables are required for analysing relationships between environmental and fisheries data. The question of whether a fishing is possible on any particular day can be answered by examining data like wave height, swell height, or wind speed and direction, where unfavourable conditions for the gear type are known. In riverine recreational fisheries, river height and flow or lake height could be used as predictor variables when examining effort.

2.5.2 Monitoring Environmental Impacts in Aquaculture

Forecasts have additional significance for aquaculture, for several reasons. For farms in open water or exposed conditions, tropical cyclones can present a major threat. Early forecasting allows protective action to be taken. For farms rearing captive animals, development of toxic dinoflagellate blooms introduces the risk of mortalities in the farmed stock, or restrictions on sales because of human health issues, depending on the species of dinoflagellate. In New Zealand these blooms have been linked with variations in the position and extent of certain ocean currents, monitoring of which can provide information on when to treat inflow water with ozone. In mussel farms, harvest must be curtailed for 48 hr following specified periods of rainfall because of the risk of contamination from increased coliform counts. In all these cases, an ability to forecast the critical events has resulted in an industry that is more adaptable to environmental variation.

2.5.3 Predicting Fish Distribution

A second factor influencing fishing success is the spatial distribution of the target species. In one respect this information is closely related to fishery access, in that it defines the area in which a fishery is operational under certain conditions. Environmental data can be used to define areas of high probability for encountering a particular species. For example, a relationship has been shown between thermal fronts and the catch per unit effort (CPUE) of broadbill swordfish (*Xiphias gladius*) by Podestá et al. (1993). The position of thermal fronts within the temperature range inhabited by the species of interest can be identified on SST maps and defined as high-probability encounter areas.

Satellite altimetry data (SSH) can provide detailed information on bathymetric features (Smith & Sandwell 1997). Seamounts have become important areas for targeting orange roughy in New Zealand waters (Clark et al. 2001). Identification of new habitat using telimetry data will extend fisheries for this and other deepwater species.

2.5.4 Determining Seasonality

The temporal distribution of a fish species can be summarized by determining the extremes of its habitat from the relationship between empirical information on areas of known presence (from catches or other data) and available environmental data.

2.5.5 Investigating Trends and Relationships

A number of studies have been performed investigating the relationship between climatic variables and recruitment or year class strength (YCS). These have used correlation analysis for a YCS index and the climatic variable in question, and regression techniques with the YCS index as the response variable.

Wind anomaly has been incorporated as a predictor in standardization of catch per unit effort (CPUE) using multiple regression techniques. This approach was based on the observation that high wind strength causes reduced effort in trawl fisheries.

2.6 RESULTS FROM WORK TO DATE — CASE STUDIES

2.6.1 Standardised CPUE indices for the southern bluefin longline fishery

A number of studies were performed (i.e. Murray et al. 1992, 1993), based on the multiple regression approach of Allen & Punsly (1984), Doonan (1991), and Vignaux (1992). These used detailed catch and effort data from Japanese foreign licensed tuna longline vessels operating in the New Zealand exclusive economic zone (EEZ), and concluded that in addition to year, season, lunar phase, SST, area, and bycatch-CPUE were significant factors in the fitting procedure.

This approach was continued annually until 1998–99, when the approach was defined more closely (Richardson et al. 2001) and a number of generalised linear and additive CPUE standardisation models investigated. A range of predictor variables were included in the fitting procedure including moon phase, SST, and SOI.

2.6.2 Climate and variable catch of striped marlin

An unpublished study was performed in 1993 that aimed to determine interactions between the recreational game fishery for striped marlin off the northeastern coast of New Zealand and the foreign licensed tuna longline fishery in the same area. The study used a multiple regression approach and included a categorical variable based on SST (Paul Taylor, NIWA, unpublished data). This predictor was eventually the most significant. It expressed the binomial case of years when, in summer, habitat water for striped marlin (defined as the isotherm of 20 °C on satellite remote sensing SST maps) migrated south on the east coast of northern New Zealand, followed by the southward migration on the west coast, with or without a two week delay beyond the first week in February. For years of higher than average striped marlin catch on the east coast, the lag occurred; in years of poor catch the lag was absent. It was postulated that there was a dilution effect in poor years, because southward migrating fish could follow shelf water on both sides of the island; in good years they were restricted to habitat on one coast that caused them to be more concentrated in one area.

2.6.3 Prediction of snapper (*Pagrus auratus*) recruitment from SST (Francis, et al. 1997)

The abstract from this study states:

“Ten trawl surveys were conducted in the Hauraki Gulf, New Zealand, to estimate 1+ snapper year-class strength (YCS), and to develop a recruitment prediction model. After correcting for changes in catchability, 96% of the variation in YCS was explained by mean sea surface temperature during February–June of the 0+ year. YCS predictions based on temperature for the 1981–1988 year classes were strongly correlated with YCS estimates for recruited snapper derived from commercial longline age-frequency data, thus validating the prediction model. Snapper recruit to the adult population at 3–5 years, enabling prediction of YCS 3–5 years before recruitment. The 1993 and 1994 year-classes were predicted to be weak or below average in strength, and the 1995 and 1996 year-classes were predicted to be above average. Forward projection of the snapper population model using predicted recruitment suggests that biomass will increase slowly at current catch levels".

2.6.4 Climatic influences on YCS of southern gemfish (*Rexea solandri*) (Renwick et al. 1998)

Correlation and linear regression were used to examine links between climate variability and recruitment of the southern gemfish. Reliable indices of year class strength were available for 12 years between 1982 and 1994 (excluding 1986). Climatological predictor variables used in the analysis were low level air flow in the form of the synoptic weather types discussed above; monthly mean SST from a global 2 ° x 2 ° gridded set derived from ship, buoy, and satellite data; and SOI. Results of this work showed that strong year classes were associated with infrequent southwesterly flow and positive SST anomalies. The simplest explanation for this impact on southern gemfish biology was temperature sensitivity. It was postulated that cooler than normal conditions at the southern limit of the gemfish range could create unsuitable conditions for reproduction and/or survival of eggs or larvae.

The physical consistency between SST and wind flow relationships and the availability of plausible explanations lends support to the idea that the results are symptomatic of a causal relationship and not merely artifacts of a small sample. It therefore seems likely that the observed decline in gemfish numbers over the last decade is in large part due to climatic influences.

2.6.5 Recruitment of the red rock lobster (*Jasus edwardsii*) (Booth, et al. 1999)

This study updated and extended information on spatial and temporal settlement patterns of this species. Larval distribution (mid-stage phyllosoma) seemed closely related to oceanic eddies. Detailed analysis of SST patterns at a very high resolution did not suggest useful information on larval distribution at this scale. Settlement rates along the east coast of central New Zealand seem to be influenced by climatic factors — highest settlement occurs in years of highest frequency of stormy, southerly weather. This analysis incorporated synoptic types similar to those described above.

2.6.6 Climate variability and YCS of hoki (*Macruronus novaezelandiae*) (Livingston 2000)

A similar method to that employed for the gemfish study summarised above was used to investigate relationships between hoki recruitment and climatic variables. The results were indicative of links between relatively strong hoki year classes and cold autumn and winter conditions as well as the southwest flow typical of negative SOI. The results support earlier observations that colder conditions tend to favour hoki larval survival in general. The study stated that:

"The increased frequency in El Niño conditions in recent years has resulted in consistently higher larval survival and higher YCSs, which have in turn given the hoki fishery a particularly positive outlook in the medium term. The wider perspective of global warming and how that may impact on hoki abundance means that climate variation will become an increasingly important part of fisheries research and stock assessment in general.

The results of this study are indicative of links between hoki recruitment and climatic conditions, and as such could be incorporated into future hoki population models to refine estimates of short-term risk. To investigate the more specific effects of climate variation on other stages of the life cycle of hoki, focused studies which explore for example, food availability, the food intake of hoki and their gonad development in autumn would be required".

2.6.7 Red cod (*Pseudophycis bachus*) stocks (Beentjes and Renwick, 2001)

An extract from the abstract states:

"The relationship between recruitment and climatic environmental variables was examined to determine if there was any causal link that might explain the variability in recruitment. The predictors sea surface temperature (SST) and Trough NW cluster [synoptic weather type], with a 14 month lag, explained 68% of variability in commercial catch in RCO 3 [red cod management area], and SST and surface westerly wind, with a 14 month lag, explained 75% of variability in commercial catch for RCO 7 [red cod management area]. These predictor variables were used to predict an environmental abundance index for input into the MIAEL model [a custom built stock assessment approach] sensitivity analysis".

2.6.8 Environmental effects on survival/growth of chinook salmon (*Onchorhynchus tshawytscha*)

The following study by G.D. James was an unpublished paper presented at the annual conference of the New Zealand Marine Sciences Society in 2000.

Correlation analysis was used to identify significant relationships between both annual survival rates and fish-condition of 1965–1991 cohorts of chinook salmon in a headwater tributary of the Rakaia River, and "five biologically relevant variables for which data were available for at least half of these years". These were SOI, SST, annual sightings of red krill (*Munida gregaria*), discharge from the Clutha river, and red cod catch in the area. The strongest correlations for both annual survival rates and fish-condition were apparent when mean SOI was lagged by 6–7 months, but these were weaker than correlations estimated for red cod and hoki in other studies, which suggests that "a more detailed understanding of climatic and oceanographic processes off the east coast of the South Island will be required before salmon survival rates can be more clearly linked to physical and biotic factors"

2.6.9 Incorporating wind data in standardisation of orange roughy CPUE (Taylor 2001)

The abstract from this study states:

"A 'combined model' (log-normal linear and binomial) stepwise multiple regression technique was used for the Auckland Islands orange roughy fishery to produce a standardised annual time series of relative abundance indices. This model provided a method of minimising the potential bias in the estimates likely to be caused by the high proportion of zero events (tows with zero catch) in the data. Data were stratified according to five areas which were included as a predictive variable in the regressions, along with fishing year, vessel, spawning season, tonnage class of the vessel, and anomalies of mean monthly wind speed at Enderby Island in the Auckland Islands group. The regressions were constrained to include fishing year in the final model. Significant predictor variables were windspeed, area, and vessel, but they accounted for only low levels of variability in the CPUE — 3% in the binomial model and 9 % in the log-linear".

2.6.10 Relationships between snapper (*Pagrus auratus*) YCS and SST (Gilbert & Taylor 2001)

As a first step, correlation between air temperature and SST in the two areas of interest were investigated with the aim of extending the time series of SST by using air temperature as its proxy. Air temperature from the two areas under investigation satisfied the tests imposed for stationarity and consistency. A maximum likelihood estimator was developed to determine relative YCS, which showed a positive relationship to spring-summer temperature for snapper stocks in both areas.

This work provided an improved method for estimating year class strength in snapper. It was concluded that for year classes where adequate data were available, YCS parameters should be estimated directly from the year classes, but SST predictors should be used where recruitment data are not adequate. These predictors will, on average, do considerably better than by assuming mean recruitment.

2.6.11 Prediction of snapper (*Pagrus auratus*) recruitment from SST (Morrison et al., 2002)

A trawl survey carried out in the Hauraki Gulf during October–November 2000 provided an estimate of snapper YCS. The snapper SST-recruitment relationship failed to predict the level of this YCS, by estimating a value much higher than that estimaed from the trawl survey. Two possible reasons were proposed.

- YCS was underestimated by the trawl survey — this would occur if a higher proportion of the 1999 year class inhabited untrawled areas, but cannot be examined until it recruits to the commercial fishery in about 2004.

- Factors (environmental and/or biological) other than SST also influence YCS.

Local variations in monthly mean SST and monthly SST anomalies over the period from immediately before spawning to the winter after spawning for the 1999 year class were compared with those for other year classes, with special consideration of particularly strong year classes in 1981 and 1989. The pattern experienced by the 1999 year class was similar to that experienced by the 1981 and 1989 year classes except that:

- monthly temperatures leading up to spawning (September–November 1998) were higher by about 1 °C;

- the 1999 year class experienced the highest January anomaly of 1.67 °C;

- monthly temperatures after spawning (June–August) were much higher.

Two explanations were proposed for the weaker than predicted YCS for the 1999 cohort.

- The high spring SST may have stimulated early snapper spawning, with the planktonic larvae experiencing unfavourable feeding conditions.

- Extensive down-welling as a result of a high incidence of easterly winds in 1999 caused caused low levels of phytoplankton production in spring 1999 (Zeldis, et al. 2001), but it is unknown whether plankton productivity affects the survival of demersal juveniles, which is stage the cohort would have reached at that time.

2.6.12 Predicting areas of high probability for tuna in the surface fisheries off New Zealand

A commercial product has been available in New Zealand for more than 10 years that provides SST maps annotated with areas of high probability of tuna catch. Separate maps are available for species whose habitat-water temperature varies appreciably, and for different areas of the New Zealand's exclusive economic zone (EEZ). Because this product became available early in development of New Zealand domestic tuna fisheries, their influence on CPUE cannot be estimated with any certainty. However the product is popular with the fishing industry from tuna longline and to trollers, some of whom state that they are assured of encountering their target species at a rate of 75% using the annotated maps. Recreational game fisherpersons also subscribe to the service.

A second, lower cost product is also available, this time from the NIWA web site. This takes the form of SST map images and requires interpretation by the subscriber. This product is popular with a range of recreational fishers.

2.7 DISCUSSION

A broad range of environmental data are available. Their utility in a fisheries/aquacultural context can be summarised according to three main levels:

- Their ability to provide information on the accessibility of a fishery, both in real time as weather forecasts, and for interpreting and summarising previous effort in a fishery.
- Their effectiveness in predicting the spatial and temporal distribution of fish, both in aiding fishers or aquacultural collectors to locate their targets in real time and for interpreting and summarising data and investigating trends in fisheries.
- Their utility in investigating relationships between particular aspects of a fishery or fished species, like the environmental factors influencing variations in YCS.

While the monitoring role of weather forecasting contrasts with the other applications summarised here because of its easy availability, its importance cannot be stated too strongly. It has widespread application for fisherpersons and collectors at all levels and its availability can be critical for the effectiveness of most fisheries and the effective management of aquacultural ventures.

Overall, there is a difference in the application of environmental data to wild fisheries and aquacultural systems. Much of the research discussed above is related to wild fisheries. While forecasting access to fisheries and identifying areas of high catch is applicable to both, albeit at a lower rate for collections for aquacultural ventures, the need for research incorporating environmental factors on farmed animals seems much less urgent. One particular area of interest is in fine scale variability of spawning and how it relates to water temperature. For captive animals at least however, this type of information might be better derived from experimental manipulations in the artificial environment, than trying to collect relevant climatic data.

The ability of fisherpersons to predict the distribution of a fish species based on increased knowledge of its biology and its relationship with environmental factors has improved their effectiveness in many fisheries, although quantifying this improvement is not always possible. Developing an understanding of these and other relationships is still in its early stages, with some patterns of variability appearing inexplicable and possibly occurring as the result of a highly complex set of inter-relationships. While we understand some of the broader effects of environment discussed here, particularly certain aspects of SST, little is known of the factors that influence the more subtle, short term changes in aspects of fish biology, like school behaviour for example.

Sometimes these environmental data have been used to improve the effectiveness of the fisherperson in the fishery. Environmental data can also be used to improve the effective management of fisheries by providing information on the factors that cause variations in surplus production. In commercial fisheries managed according to a strategy of maximum sustainable yield (MSY), knowledge of fluctuations in surplus production is fundamental to setting catch limits in the fishery. The basis of surplus production is the level of recruitment over some period, which is quantified as indices of YCS.

The results of a number of the studies summarised above provide a basis for predicting YCS in particular species. They also provide a model for examining other species for the influence of environmental factors on year class strength and represent a step in the right direction to realising the research path proposed by Renwick et al. (1998), that "there is a real need [from a New Zealand perspective] to carry out more correlative analyses, on a wide range of species, to determine how prevalent such climate interactions are and to predict the likely effects of climate variability and change on our marine populations".

Good management is based on reliable information, which allows prediction of catch rates. The SST-related model for red cod catches (Beentjes and Renwick 2001) has been successfully applied for prediction of catch off the South Island east coast over the past three years. The SST-recruitment method of predicting YCS (Francis et al. 1997) failed when applied to data for 1999, but this was probably the result of extreme temperature at critical times (Morrison et al. 2002), a contingency that had not been built into the model. Such improvements refine the methods and eventually result in reliable predictions being made.

Synoptic weather types provide models of wind flow. Each is accompanied by a characteristic set of variations in other environmental factors like cloud cover, air temperature, and rainfall. As a group these types have consistently been significant as predictor variables in regression models investigating YCS in finfish and crustacean larval distribution. Generally they have proved useful in this work and their development has proved an important step in understanding the relationships summarised here.

ENSO events are also important in New Zealand, but the mechanisms by which fisheries are impacted are not well understood. Although some aspects of the South American system are duplicated by climatic conditions on the northeast coast of the North Island, links with fish and fisheries must remain largely speculative at this time, mainly because of the lack of information available on the biology of key species like pilchards (*Sardinops neopilchardus*) and anchovy (*Engraulis australis*). This final point highlights an inescapable fact in this type of work, that, in developing our understanding of the relationship between animals and their environment, the requirement for reliable, relevant information on their biology is equally as important as the requirement for reliable, relevant environmental information.

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