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Adaptation of fisheries and mariculture management to extreme oceanic environmental changes and climate variability in Taiwan

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ABSTRACT

This study presents the response of fisheries management to the extreme climatic events that affect marine capture fisheries and mariculture in Taiwan. Two regional approaches that can be applied universally to help capture fisheries and mariculture adapt to extreme weather events are also proposed. In the winter of 2008, an anomalously strong and continuous northeasterly wind caused by a La Niña event drove the cold China Coastal Current southward to penetrate the southern Taiwan Strait, and a portion of this current intruded eastward to the southern Penghu Archipelago. The cold current intrusion appreciably damaged marine aquaculture and the wild fish population, causing the death of more than 73 t of wild fish and 80% of cage aquaculture fish at the Penghu Islands. This extremely cold seawater event occurred between late January and the beginning of February 2008. To recover fishery resources around the waters of Penghu, fishery-related agencies adapted recovery measures over 3 years starting in April 2008 that included hatchery juvenile release, environmental monitoring, fishery subsidies, and ecological field investigations. This study suggests that responding to extreme climatic influences on fisheries and mariculture should include (1) establishing an early warning system by connecting fisheries agencies and marine research institutions to assist decision makers in performing time-adaptive measures, (2) temporarily suspending fishing activities after the occurrence of a natural disaster to help recover fishery resources and ecosystems, (3) altering the governance of farming fishing right so that fish farmers can temporarily transfer their aquaculture cages from high-risk areas to waters outside the influence of extreme weather events, and (4) continually filing surveys to understand the recovery status of marine ecosystems.

1. Introduction

The effects of climate change on global marine ecosystems and fisheries are difficult to predict. However, regional research indicates that climate variability and change damaged some fish stocks. Changes in the marine environment in upwelling zones can result in not only a decrease, but also a shift in the population of lower trophic species [1]. Extreme rainfall can affect ocean circulation and alter marine life habitats. Increasing seawater temperatures limit primary production, increase the rate of coral bleaching, and decrease the biodiversity of some ecosystems. Research on climate change or climate variability and fisheries has focused mainly on documenting trends and fluctuations in fish abundance, distributions in oceanic regime changes, and the population of major pelagic fishes with high commercial value [2]. Some studies have examined extreme oceanic changes and their influence on coastal fisheries and ecosystems. In recent years, several local studies have examined how climate variability and change affect marine organisms [3,4]. However, an analysis of the vulnerability and adaptability of fisheries and fisheries management communities is still lacking.

Climate change can cause rapid changes in marine environments and in marine organism dynamics. It can increase seawater temperature, change hydrologic patterns, cause rare and extreme oceanic events to occur, and decrease the population of marine fish [5–7]. Previous studies focused mainly on pelagic waters; however, increasingly more research is focusing on the relationship between climate change and variations in fish abundance in regional waters. Extreme global weather events related to climate change have increased since the 1990s, and they have influenced capture fisheries and maricultures significantly. In the Asia Pacific region, climate change has induced extremely high and low water temperature anomalies, which can change the fish spawning season and feeding grounds, and decrease the hatching rate and

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population of captured fishes [8,9]. Extreme weather can also affect aquaculture because high water temperatures reduce the growth rate and the stock of fry, thereby impacting the economy and society [10–12]. Hsieh et al. [13] and Chang et al. [4] reported the occurrence of an extreme low water temperature event in February 2008 that resulted in the death of wild fish surrounding the coasts of the Penghu Archipelago (PHA) in the southern Taiwan Strait (TS). The cold water event wreaked havoc on marine resources and on the coral reef ecosystem, and consequently, many coastal fisheries declined sharply over the following years. The death of most cage-culture fish around the PHA from the 2008 cold water event also caused an economic loss of more than US$10 million. The relationship between fishery catches and extreme changes in the marine environment is not yet clearly understood.

Although extreme weather events produced by climate change are not predictable, fisheries policymakers and managers can take precautions against such events and establish a decision-making framework that can help fishers collectively adapt to the extreme weather events and the economic risks of climate change. Fisheries agencies are usually managed through policies; however, scientific investigations and statistical analyses are the primary reference points for decision makers. This study, therefore, includes scientific analyses of information gathered from fishing recorders and environmental monitoring data to investigate the influence of specific climate forces on coastal fisheries and cage farming in the southern TS. Furthermore, this study offers a guide for policymakers and fisheries managers to adapt marine capture fisheries and cage aquacultures in Taiwan to extreme climatic changes.

2. Effect of extreme temperature events on marine and cage culture fisheries in Taiwan

The specific effects of climate change on capture and aquaculture fisheries in Taiwan are difficult to predict and quantify. However, recent studies indicate that extreme weather and marine environmental changes induced by climate change harms the marine fish population and aquaculture. Satellite-derived sea-surface temperature images show that the distribution of winter oceanic currents in the Taiwan Strait is dominated mainly by the cold China Coastal Current in the west and the warm Kuroshio Branch Current in the east (Fig. 1a). In winter, the cold current in the western TS moves mainly southward along the Chinese coast, and a portion of the current is blocked around the northern PHA and returns northward. Simultaneously, the warm current from southern Taiwan is blocked by a portion of the cold current. Previous studies [14,15] on water temperature patterns in the strait indicated that the dominant spatial variance in water temperature in winter was consistent with a quasi-permanent front at the northern PHA. Based on most previous studies, the cold current was generally thought to be blocked north of the PHA in winter, whereas areas around the PHA were surrounded by warm, highly saline water (Fig. 1a). However, in the winter of 2008, the cold China Coastal Current moved southward to penetrate the southern Taiwan Strait, and a portion of this current with temperatures lower than 18 °C intruded eastward to the southern PHA (black arrow in Fig. 1b).

Water temperatures in the PHA are affected by seasonal current circulation patterns and occasionally by extreme climate changes, which occurred during El Niño events, characterized by increasing water temperatures, and La Niña events, characterized by abnormal temperature drops [14]. Water temperature in the southern TS is generally above 20 °C in winter, but it dropped to 13 °C between the end of January and the middle of February 2008. This extreme thermal anomaly had a significant impact on marine ecology and fisheries. In January and February 2008, many resident fish were found dead on the PHA beaches, with more than 183 species in 58 families recorded dead, including large numbers of highly priced species such as the grouper, parrotfish, and wrasse. Regions of bleached coral have also been found [13]. The low water temperature event thus significantly damaged marine aquaculture and wild fishes, and caused the death of more than 73 t of wild fish and 1500 t of cage aquaculture fishes in PHA. Fig. 1(d) and (e) shows dead fish washed on the coast. This ecological disaster was thought to have been caused by the exceptional intrusion of cold current produced by climate change [4,13].

A similar cold water event occurred again in the winter of 2011. As shown in Fig. 1(c), sea surface temperature surrounding the PHA dropped below 18 °C, and the isotherm of 20 °C (black contour) retreated to the southern PHA. More than 70% of cobia (*Rachycentron canadum*), a major species of cage culture, died at the end of January, and more than 500 t of caged fish were cleaned in 1 week by fish farmers (Fig. 1f). Although changes in water temperature during La Niña caused more intense hydrographic variations and damage to fisheries and aquaculture than

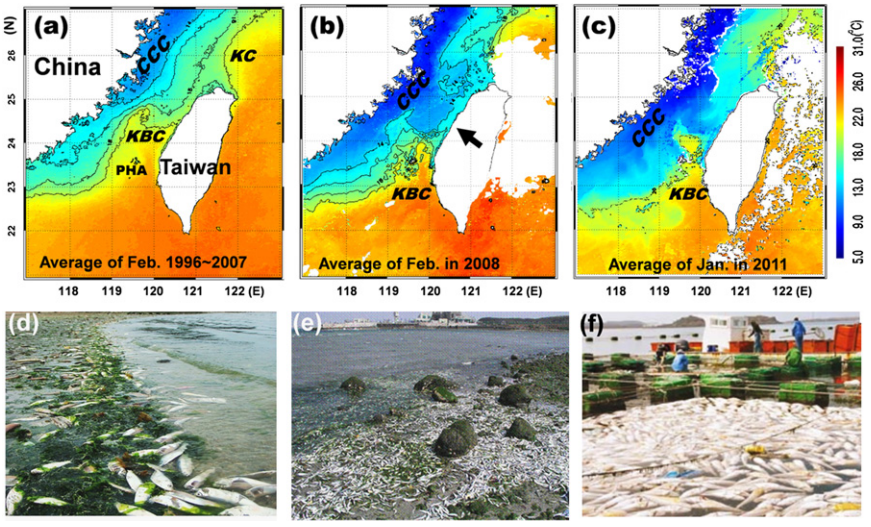

Fig. 1. SST images of winter periods in the Taiwan Strait over a long-term average (a), February 2008 (b), and January 2011 (c). CCC, KBC, and KC represent the China Coastal Current, Kuroshio Branch Current, and Kuroshio Current, respectively, and PHA represent the Peng-Hu archipelago. Dead fish washed onto the beach in the Peng-Hu archipelago in February 2008 after a cold water event (d, e); and dead cobias in cages, 2011 (f).