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# From subsidy evaluation to effort estimation: Advancing the function of voyage data recorders for offshore trawl fishery management

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ABSTRACT

The overfishing of large vertebrates and shellfish is the first major disturbance to all the valuable coastal ecosystems that have been studied. However, usable logbook data has not been required or of concern in many small-scale fisheries operating in the coastal or offshore regions, rendering impact evaluation and further management difficult. Various studies have taken advantage of vessel monitoring systems (VMSs) that were originally developed for purposes such as surveillance, to derive high-resolution spatiotemporal effort data or further develop logbook-like data. These systems are usually installed on large-scale fishing vessels but seldom on small-scale vessels. Taiwan provides fuel subsidies to fishery operations, evaluated according to active moving hours at sea, as calculated with customized voyage data recorders (VDRs) that have been installed on most small-scale offshore fishing vessels. The device provides temporal position and speed data similar to that of VMSs, not in real time but with cheaper device cost, no data transmission fee and higher resolution at 3-min intervals. This paper takes the offshore trawl fishery of southwestern Taiwan as example to demonstrate that the VDR data used for subsidy evaluation could also be used for high-resolution effort estimation. After briefly documenting the development of Taiwanese trawl fisheries and the application of VDR in Taiwan, the paper proposes a simple five-step procedure for managers to categorize major fishing patterns of fisheries by reviewing the speed and track profiles of vessels on a trip-by-trip basis, and finally to develop speed criteria for defining fishing efforts.

## 1. Introduction

Coastal waters are among the most productive ecosystems on the planet and, through ecosystem services such as coastal protection and habitat–fishery linkages, greatly contribute to the fulfillment of human needs [1,2]. However, coastal ecosystems currently face serious anthropogenic threats, with the overfishing of large vertebrates and shellfish being the most serious [3,4]. This region has been heavily exploited by small-scale[1] coastal and offshore fisheries, among which trawl fisheries constitute the greatest impact on the seabed [8,9].

Numerous small-scale fisheries worldwide are not required to report their logbook data, or, similar to large-scale fisheries, the quality of the data is suspect for fishery research purposes due to the nature or unreliability of the data [10–12]. Large-scale fisheries, because of their capital-intensive nature and high profits, can usually afford to install vessel monitoring systems (VMSs) or implement observer programs with certain coverage rates. These requirements have incidentally made available high-quality or high-resolution data to scientists for performing fine-scaled fishery research, such as the validation of logbook positions, definition of fishing grounds, or exploration of the spatial distribution of effort at high resolutions [13–17], as well as facilitating the formulation of management suggestions to protect fish stocks or the implementation of marine spatial planning to minimize marine resource conflicts among various sectors [10,16].

As for small-scale fisheries, due to the large number of fishing vessels and their low-capital nature, VMS installation is usually not possible unless the expected profit or impact is substantial (e.g. precious coral fishery [18,19]). Coastal surveillance radar systems (CSRSs), which do not require installation and provide free positional data, have been applied to derive the spatial distribution of fishing effort [20,21]. However, CSRSs require a mechanism to determine vessel identity and are easily affected by environmental factors such as cloudy weather and large waves.

Most countries with large fishing sectors have subsidized the development of their fisheries for context-specific reasons [22]. Despite ongoing arguments on the negative environmental impacts of

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[1] The definition of "small scale" may differ according to the circumstances in each country, such as fishing locations, the nature of objectives, and vessel sizes [5,6]. Taiwan defines fisheries that mainly operate in waters within 200 nautical miles of the coast as offshore or coastal fisheries and those operating in waters beyond this boundary as distant-water fisheries [7]. However, in practice, small-scale offshore or coastal fisheries are those with vessels < 100 gross registered tonnage (GRT) (including "medium-scale" vessels) with fish products mainly intended for local consumption, in contrast to large-scale distant-water fisheries with vessels ≥100 GRT (http://goo.gl/YgPF0o).

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subsidies, numerous factors have prevented their removal from industry management plans [23,24]. Taiwan has provided fuel subsidies to fishing vessels since 1958 [25]. The amount of subsidy to fishing vessel was initially evaluated on the basis of the length of time a vessel "stayed" at sea. Revisions to this evaluation scheme were enacted in 2007 to be based on the length of time a vessel is "actively moving" at sea, with the objective of reducing fraud [25]. A more detailed explanation of this system is provided in Section 2.2. These evaluations are conducted using 3-min interval position records obtained from low-cost customized voyage data recorders (VDRs). The Fisheries Agency (FA) of Taiwan subsidizes the installation of VDRs on fishing vessels that request fuel subsidies.

Historically, the offshore trawl fishery has contributed the highest proportion of offshore catches in Taiwan with the record high of 60% in 1980. Although the industry has been criticized for decades over its degradation of coastal and offshore ecosystems, logbooks are still not required for evaluating environmental impact. The landing data of fisheries are available from fish markets, and exhibit a certain degree of accuracy. If fishing effort could be estimated using VDR data, then the construction of logbook-like data similar to [21] would be possible. This paper investigated the utility of VDR, originally intended for subsidy evaluation purposes only, to gather high-resolution estimates of spatiotemporal fishing effort. As a test case, the paper analyses VDR data from a trawl fishery off the southern coast of Taiwan, one of the most important trawling ground in Taiwan. If deemed feasible, the results can be used for the exploration of fishery dynamics and as a basis for establishing fishery management measures.

This paper first briefly documents the development of the trawl fishery and the application of low-cost VDR in Taiwan in Section 2. Section 3 introduces procedures for defining speed criteria in effort estimation from VDR data. The results are provided in Section 4 on categorized fishing patterns, speed criteria inferred from the patterns, and the implications of the estimated distribution of fishing effort. Finally, Section 5 discusses the benefits of using VDR for subsidy evaluation and effort estimation, as well as the procedures for defining speed criteria.

## 2. Trawl fisheries and VDR in Taiwan

### 2.1. Trawl fisheries

Trawl fisheries were introduced to Taiwan by way of Japan in the 1920s, developing rapidly after 1953 when the government initiated the first of five phases of the Four-Year Economic Construction Plan to promote investment in coastal and offshore fisheries damaged in World War II [26–28]. Approximately 50 trawlers were in operation in 1949, increasing to 278 (including otter and bull trawlers) in 1959 [28]. Following this increase in trawlers, fishing grounds expanded from Taiwanese coastal and offshore areas to the East China Sea, Yellow Sea, South China Sea, and further to the exclusive economic zones (EEZs) of other countries [29]. Heavy exploitation by the trawl fisheries damaged fishery resources and regional ecosystems. To curtail the number of small trawlers fishing in coastal and offshore waters, Taiwan implemented the first of seven Vessel-Building Restriction Programs (VBRPs) in 1967 [26]. However, implementation of the program resulted in an increase in large trawlers in both offshore and distant waters. The number of large trawlers had increased further to 1064 in 1986 as a result of the second through fourth VBRPs [29], but these vessels mainly fished in distant waters. Later, the number of trawlers was frozen by the fifth program implemented in 1988 for prohibiting the construction of trawlers of any size, and further reduced by the implementation of a 5-year buyback program for all aged vessels in 1991 and a 3-year buyback program specifically for large vessels in 2007 [26,30]. The last distant-water bull trawler was brought back in 2008.

The catch in trawl fisheries increased rapidly in the 1960s, with

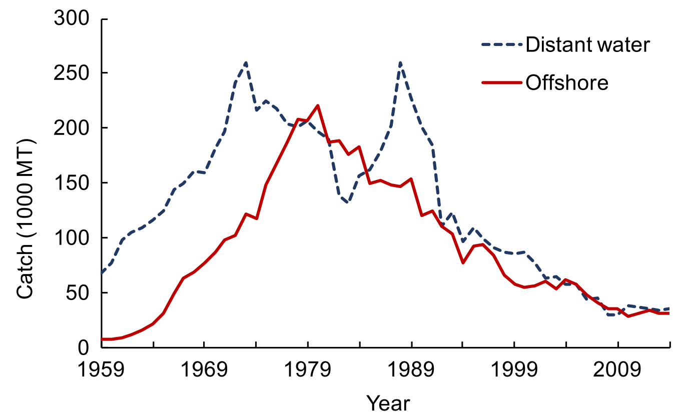


**Fig. 1.** Catch trends among Taiwanese distant-water and offshore-trawling fisheries during 1959–2014.

distant-water catches consistently higher than offshore catches by approximately 100,000 mt (Fig. 1). The differences were much higher in the early 1970s, when a favorable fishing ground off the northern Australian coast was explored. A record high catch of 260,000 mt was recorded in 1973. However, the oil crises in 1973 and 1979 and the declarations of EEZs by many coastal countries after 1977 caused a substantial decline in distant-water fisheries until the mid-1980s, when another promising fishing ground off Indonesia was found. Historically, the major grounds for this type of fishery shifted from the coast of mainland China and the Taiwan Strait during 1949–1954, to the Sunda Shelf of the South China Sea during 1954–1963, to northern Australian waters [31] and Indian waters during 1963–1986, and finally to the waters of Indonesia, the Middle East, and Africa since 1986 [32]. The serial depletion of resources was common in this fishery over time and by 2014 the catches declined to 32,000 mt.

After the first VBRP restricted building of new vessels < 20 GRT, more large-sized offshore vessels were built and catches substantially increased after 1967, peaking at 220,000 mt in 1980. However, similar to the fate of distant-water fishery, offshore trawl fishery catches declined dramatically in recent years as a result of the overexploitation of offshore and coastal fishing grounds.

A total of 185–200 offshore trawlers are currently active in Taiwan. Their major fishing grounds are in northeastern Taiwan and the continental shelves between western Taiwan and mainland China. More than half of the vessels are registered in counties or cities in southwestern Taiwan. Most trawlers in this region belong to size categories CT2 and CT3[2] (87%), including beam, otter, and bull trawlers.

The total catch of Taiwanese offshore trawl fisheries was approximately 32,000 mt in 2014. Over one-fourth of this catch was landed in the fishing ports of southwestern Taiwan [7]; and comprised more than 200 species from diverse offshore ecosystems. Approximately 40–50% of the 2014 catch comprised unclassified species from an estimated 30 families; some of them were juveniles of commercial species and others were categorized as "trash fish." The rest belonged to major commercial species, including Carangidae, Cephalopoda, Sciaenidae, Stromateidae, Sparidae, and shrimp.

### 2.2. VDRs

The Maritime Safety Committee (MSC) of the International Maritime Organization has required that passenger ships and other large ships carry a standard VDR to assist in accident investigations

[2] Size category for motive fishing vessels in Taiwan are denoted by "CT" plus one digit: 0 for < 5 GRT, 1 for 5–9 GRT, 2 for 10–19 GRT, 3 for 20–49 GRT, 4 for 50–99 GRT, 5 for 100–199 GRT, 6 for 200–499 GRT, 7 for 500–999 GRT, and 8 for ≥1000 GRT.