南華大學
Nanhua University

2023-2024永續發展目標報告書

生命教育
Life Education

智慧創新
Intellectual Innovation

環境永續
Sustainable Environment

三好校園
Three Acts of Goodness

2025年10月

Objective 14: Life below Water

Abstract

Nanhua University actively pays attention to sustainable development issues. In addition to actively treating wastewater, it encourages teachers to participate in the conservation and sustainable use of oceans and marine resources, prevent the marine environment's degradation and contribute to the ocean's sustainable development.

The university actively treats wastewater by setting up sewage treatment plants and establishing wastewater treatment processes. The treatment system adopts mechanical trash racks, primary sedimentation tanks, adjustment tanks (T01-3), aeration tanks (T01-4), final sedimentation tanks, intermediate tanks, sand filter buckets, drainage tanks, and sludge tanks, sludge dewatering machines, and other methods. Furthermore, drainage water quality testing is implemented every six months. In the 2022-2023 academic year, the treatment volume of reclaimed water was 95,563 m^3, the water used for reclaimed irrigation was 34,276 m^3, and the recycling rate was 35.50%.

Associate professor Yu-Min Yeh of our University has been implementing several scientific and technological projects funded by the Fisheries Agency, Council of Agriculture, Executive Yuan, ROC, for many years and has served as an administrative scientist of Fisheries Agency. As a Taiwan delegate, Dr. Yeh participates in many Regional Fisheries Management Organization meetings and publishes scientific research reports every year. Dr. Yeh devotes to the sustainable development of Taiwanese fisheries and marine resources. In the past ten years, Dr. Yeh has presided over more than seventeen projects funded by the Ministry of Science and Technology and the Fisheries Agency. The research focuses on assessing and managing tropical fishery resources of bigeye and yellowfin tuna in the Indian Ocean and the offshore and coastal fisheries around Taiwan. The application fields are mainly divided into three categories, impact assessment of the pelagic tuna longline fishing activities on seabirds and evaluation of mitigation measures to reduce incidental catch of seabirds, the assessment and management of tropical tuna fishery resources of Indian Ocean bigeye and yellowfin tuna, and the temporal and spatial distribution of fishing vessels operating in the coastal waters of Taiwan as well as estimation of the total catch.

For example, in the project titled "CPUE index and stock assessment of Taiwanese tropical tunas in the Indian Ocean" funded by Fisheries Agency in 106-108, the findings were (1) In tropical regions, the fishing strategy can be determined by the catch composition of bigeye tuna, yellowfin tuna, and oil fish combined with fishing year. In the eastern tropical zone, the fishing strategy is changed with fishing years. The northern part of the western tropical zone did have different fishing strategies depending on the latitude. (2) The catch composition of albacore, oil fish, swordfish, and southern

bluefin tuna in temperate waters, as well as the fishing year, are the main factors determining the fishing strategy. In western temperate waters, the fishing strategy changes with fishing years. This result echoes the development of oil fishery in 2006. The eastern temperate zone waters have different fishing strategies with the fishing year's change; moreover, several specific fishing vessels have unique fishing strategies. In the past ten years, Dr. Yeh has been invited by the Fisheries Agency to participate in more than 20 international conferences and has published more than 20 scientific reports on those international conferences. Recently, Dr. Yeh participated in the "The Sixth IOTC CPUE Workshop on Longline Fisheries" in 2019 and made three recommendations for international fisheries management. One is that representatives of the purse seine industry participating in the meeting raised doubts about the inconsistency between the assessment results of IOTC bigeye and yellowfin tuna resources and the current situation. It is believed that the CPUE index adopted in the stock assessment model may cause the evaluation result to be biased due to ignoring the discard amount. The second is that the proportion of yellowfin tuna discarded reported by Taiwanese fishery from 2017 to 2018 has increased significantly compared to previous years. The reporting of discard data will become important in the future. It is recommended to strengthen the discard reporting by industry to increase Taiwanese longline fishery's discard reporting rate. The third is that, in the future, the availability and reliability of operational level catch data by Taiwanese small-scale longline fishery should be checked to meet the CPUE working group's needs at that time.

「Goal 14：Underwater Life」 From August 2022 to July 2023, the main results are as follows:

Index	**Quantity**	**Remark**
Reclaimed water treatment capacity (m^3)	90,198	
Reclaimed water irrigation usage (m^3)	29,339	
Reclaimed water recycling rate (%)	32.53	Tracking results year by year
Number of studies related to ocean and water	19	

目標 14：水下生命

(Life below Water)

摘要

本校積極關注永續發展議題，除積極處理廢水外，更鼓勵教師參與保育及永續利用海洋與海洋資源，防止海洋環境劣化，為海洋永續發展盡一份心力。

本校積極處理廢水，設置污水處理廠，建立廢水處理流程，採取機械攔污柵、初沉池、調節池(T01-3)、曝氣池(T01-4)、終沉池、中間池、砂濾桶、放流池、污泥池、污泥脫水機等處理設施，每半年實施放流水水質檢測。2024 年中水處理量 90,198 m^3、中水澆灌用水 29,339 m^3，回收使用率 32.53%。

本校葉裕民教授透過長年執行漁業署多項科技計畫，擔任漁業署行政科學家，每年代表台灣參加國際漁業管理組織會議，發表科學性研究報告，為台灣漁業與海洋資源與永續發展而努力。葉裕民教授近十年來主持行政院科技部、農業委員會漁業署的研究計畫，主要者多達 17 項。研究重點主要著重於台灣本島及印度洋大目鮪與黃鰭鮪熱帶鮪類漁業資源評估與管理。應用領域主要分三大類，遠洋鮪延繩釣漁業活動對於海鳥的衝擊評估與降低海鳥混獲忌避措施之研究、印度洋大目鮪與黃鰭鮪熱帶鮪類漁業資源評估與管理以及台灣沿近海作業漁船時空分布解析及漁獲量推估。

以 106-108 年葉裕民教授主持行政院農業委員會科技計畫「印度洋熱帶鮪類資源研究」為例，研究發現：(1)在熱帶區域，大目鮪、黃鰭鮪、油干的漁獲量以及作業年代是主要判定作業策略的因子，東熱帶區域，作業策略是隨著不同的作業時期(年代)而有所改變。西熱帶區域的北部則會因緯度的高低，會有不同的作業策略。(2)溫帶水域長鰭鮪、油干、劍旗魚與南方黑鮪的漁獲量以及作業年代是主要判定作業策略的因子。西溫帶水域，作業策略是隨著不同的作業時期(年代)而有所改變，這個現象呼應了 2006 年油干漁業的發展。東溫帶水域隨著作業時期的改變，會有不同的作業策略，而且有幾艘特定的漁船有其獨特的作業策略。本校葉裕民教授近十年來，獲行政院能農業委員會漁業署邀請參加二十幾次國際會議與發表二十幾篇國際會議科學報告。近期葉裕民教授於 2019 年參加「IOTC CPUE 標準化工作小組會議」，提出檢討與建議有三，一為，本次參與會議之圍網業者代表對於 IOTC 大目鮪與黃鰭鮪資源評估結果與現況不符產生質疑，並認為資源評估模型中之 CPUE 序列可能因忽略丟棄量而導致評估結果出現偏誤。二為，2017-2018 年我國黃鰭鮪丟棄量比例相較歷年明顯上升，未來對於丟棄量資料收集將顯得重要，建議後續應加強對業者宣傳丟棄量回報之重要性，以期提升我國丟棄量回報之比例。三為，後續對於小釣作業層級資料應先行檢視可利用性，以便因應屆時 CPUE 工作小組提出該資料之需求。

在 113 年葉裕民教授主持國科會計畫「減輕臺灣魷延繩釣船在東南大西洋作業時海鳥混獲問題的最佳做法」，研究針對臺灣白鮪延繩釣船在東南大西洋的海

鳥混獲問題，評估趕鳥繩、加重支繩與夜間放線三項減緩措施的效果。結果顯示，夜間放線最能有效降低混獲率；趕鳥繩可在其有效範圍內驅離海鳥，但餌鉤離開範圍後效果下降；加重支繩可減少逾六成混獲，但可能降低白鮪漁獲。最佳做法為趕鳥繩搭配加重支繩，並確保餌鉤在離開趕鳥繩保護範圍前沉至海鳥無法觸及的深度，以兼顧保育與漁業效益。

「目標 14：水下生命」2024 年主要的成果數據如下表。

指標	數量	備註
中水處理量(m^3)	90,198	
中水澆灌使用量(m^3)	29,339	
中水回收使用率(%)	32.53	逐年追蹤成果
海洋及水域相關研究數量	19	

目標 14：水下生命(Life below Water)

目錄

目標 14：水下生命

本校積極參與保育及永續利用海洋與海洋資源，防止海洋環境劣化，以確保永續發展。世界各國已體悟全球海洋資源之利用已接近飽和甚或至過度，如何適當的管理保育與合理的開發是使資源得以永續利用刻不容緩的議題。台灣沿近海漁業與遠洋漁業都是台灣重要的產業，尤其台灣遠洋漁業船隊規模龐大，在全球首屈一指，所以台灣對於全球漁業資源的保育與管理責無旁貸。

台灣已是三大洋遠洋漁業大國，對於公海資源，尤其是鮪旗類資源狀態的掌握，台灣的漁獲統計相關資料實屬不可或缺。考慮商業性漁捕行為的發展對漁業目標物種資源的影響是重要的議題外，然在環保意識高漲的國際社會，其對於意外捕獲物種所帶來的衝擊，亦發是不容忽視的問題。

台灣遠洋鮪延繩釣船隊規模龐大，且部分作業區域和多種保育類海鳥分布範圍重疊，為確實掌握遠洋鮪延繩釣業目標魚種漁撈作業和意外混獲物種狀況，台灣長期派遣科學觀察員登船紀錄相關資訊。本校與葉裕民教授長期與漁業署合作，擔負起責任制漁業應盡的責任與義務，執行行政院農業委員會漁業署相關科技計畫，分析觀察員資料，對於鮪延繩釣漁業意外捕獲海鳥狀況進行科學性且信賴度高的量化評估。合作範圍包括台灣沿近海漁業基礎漁獲資料的蒐集、沿近海漁業漁場熱點分析與漁撈作業動態解析、遠洋鮪延繩釣漁業資源評估與管理相關之各類科學行政與研究工作。葉裕民教授透過長年執行漁業署多項科技計畫，擔任漁業署行政科學家，每年代表台灣參加國際漁業管理組織會議，發表科學性研究報告，為台灣漁業與海洋資源與永續發展而努力。

葉裕民教授歷年來的研究重點主要著重於台灣本島及印度洋大目鮪與黃鰭鮪熱帶鮪類漁業資源評估與管理。應用領域主要分三大類，遠洋鮪延繩釣漁業活動對於海鳥的衝擊評估與降低海鳥混獲忌避措施之研究、印度洋大目鮪與黃鰭鮪熱帶鮪類漁業資源評估與管理以及台灣沿近海作業漁船時空分布解析及漁獲量推估。

公海漁場與資源日趨減少，臺灣沿近海漁業亦應更加重視。葉裕民教授多年執行行政院農業委員會漁業署相關科技計畫，應用多種漁業科學研究方法蒐集作業漁船樣本戶漁撈作業紀錄，解析台灣商業性鮪延繩釣漁業漁獲統計資料與觀察員資料，並結合漁業署港口訪查資料與漁業署安裝在我國漁船之航程記錄器(Vessel Data Recorder, VDR)所蒐集到的漁船航程作業地理資訊。藉此掌握漁船作業動態，解析台灣沿近海主要漁業作業漁場之時空分布情形及其主要漁獲魚種資源之分布動態，提供科學管理建議，以利台灣漁業管理機關訂定台灣沿近海漁業管理措施。同時應漁業署邀請擔任行政科學家，長年參與國內各類漁業管理科學會議，更代表台灣參與國際漁業組織印度洋鮪類委員會(Indian Ocean Tuna Commission, IOTC)之科學委員會會議發表科學性研究報告。

壹、行政院科技部、農業委員會漁業署的委託研究

本校全力支持海洋資源研究，葉裕民教授主持行政院科技部、農業委員會漁業署的主要研究如下表 2-1：

表 2-1　本校葉裕民教授主持的海洋資源研究

年度	計畫名稱	計畫編號
113	Best practices for mitigating seabird bycatch on Taiwanese albacore longline fishing vessels operating in the southeastern Atlantic Ocean	
109	印度洋熱帶鮪類資源研究	科技部 C101000367
109	愛麗絲夢遊仙境職場-動物換位思考	科技部 C109000343
108	科-海鳥群聚與海鳥攻擊魚餌率與混獲率之關聯分析	科技部 C108000074
107	印度洋熱帶鮪類資源研究	107 農科-9.1.2-漁-F2(2)
106	印度洋熱帶鮪類資源研究	106-農科-10.1.2-漁-F1(Z)
106	臺灣沿近海西部漁業活動之調查研究	106 農科-10.2.3-漁-F1(2)
105	印度洋熱帶鮪類資源指標暨資源評估研究	105 農科-11.1.2-漁-F1 (3)
105	臺灣沿近海西部漁業活動之調查分析	105 農科-11.2.3-漁-F1 (3)
103	印度洋熱帶鮪類(大目鮪及黃鰭鮪)資源研究	103 農科-11.1.1-漁-F2(3)
103	臺灣沿近海刺網漁業活動之調查研究	103 農科-11.2.1-漁-F1(2)
102	印度洋熱帶鮪類(大目鮪及黃鰭鮪)資源研究(CPUE 標準化)	102 農科-11.1.1-漁-F2(2)
102	臺灣沿近海刺網漁業活動之調查研究	102 農科-11.2.1-漁-F1(2)
101	印度洋熱帶鮪類(大目鮪及黃鰭鮪)資源研究(CPUE 標準化)	101 農科-11.1.1-漁-F2(2)
101	降低海鳥混獲忌避措施之研究	101 農科-11.1.1-漁-F9

年度	計畫名稱	計畫編號
101	臺灣沿近海刺網漁業活動之調查研究	101 農科-11.2.1-漁-F1(3)
100	印度洋熱帶鮪類(大目鮪及黃鰭鮪)歷史資料檢視暨 CPUE 標準化研究	100 農科-10.1.1-漁-F2(3)
100	臺灣沿近海刺網漁業活動之調查研究	100 農科-10.2.1-漁-F1(3)
99	印度洋大目鮪及黃鰭鮪 CPUE 標準化及資源評估	99 農科-10.1.1-漁-F2(2)

貳、印度洋熱帶鮪類資源研究

本校葉裕民教授主要著重於台灣本島及印度洋大目鮪與黃鰭鮪熱帶鮪類漁業資源評估與管理。茲以 106-108 年葉裕民教授主持行政院農業委員會科技計畫「印度洋熱帶鮪類資源研究」為例，予以說明。

行政院農業委員會有感於印度洋熱帶鮪類資源的重要，委託葉裕民教授主持為期三年的「印度洋熱帶鮪類資源研究」，研究重點報告，參照附件 1 至附件 3。三年研究報告的摘要依序如下。

一、印度洋熱帶鮪類資源研究(I)：106 年

依本年度全程計畫目標檢視與分析我國印度洋熱帶鮪類作業層級資料與觀察員資料之漁獲與體長資料，以掌握漁業利用資源動態發展。並進行印度洋大目鮪與黃鰭鮪 CPUE 標準化研究分析，以因應 2017 年國際漁業組織印度洋鮪類委員會(IOTC)熱帶鮪類資源指標更新評估。

根據觀察員資料進行印度洋大目鮪與黃鰭鮪體長與體重關係式估算，印度洋大目鮪體長與體重關係式估算為 $\boldsymbol{W_i = 0.0000214L_i^{2.98211}}$，印度洋黃鰭鮪體長與體重關係式估算為 $\boldsymbol{W_i = 0.00059L_i^{2.794842}}$。

今年四度進行延續性進階國際合作，在台日韓與塞席爾四國作業日誌資料的保密性已充分考慮下，由 IOTC 外聘僱問整合四國作業層級的漁獲作業資料，估算出最具代表性的鮪延繩釣漁業印度洋大目鮪與黃鰭鮪的單位努力漁獲量標準化序列，提供與 2016 年印度洋鮪類委員會(IOTC)熱帶鮪類工作小組進行印度洋大目鮪與黃鰭鮪魚種資源評估。

本研究根據我國之漁獲資料採用國際合作發展出的研究分析架構以及 R 程式碼進行 CPUE 標準化序列，以利後續之分析比較。根據往年的先期研究對於我國漁業與漁業資料之概況與特性深度剖析，更新定義大目鮪與黃鰭鮪於資源評估用的統計漁區，並利用群集分析法區別出各漁業在各統計區的作業策略，並將此結果作為標的魚種的替代資訊，後續進行大目鮪與黃鰭鮪的 CPUE 標準化時，可以用群集組別效應納入模式以估算更適當的 CPUE 標準化序列。

經由四年的國際合作研究，依據分析結果，形成許多觀點與建議可供後續在資料處理與研究方向上參考。整體而言，透過深度的國際合作處理，長久以來關於印度洋熱帶鮪類 CPUE 標準化序列趨勢不確定性的緊張情勢已在今年的資源評估工作上已大幅緩解。漁業署已與 IOTC 及其他會員國達成共識，支持此一國際合作計畫，相信對於我國的形象與漁業資源評估的可信度皆有所提升。

二、印度洋熱帶鮪類資源研究(II)：107 年

今年四度進行延續性進階國際合作，在台日韓與塞席爾四國作業日誌資料的

保密性已充分考慮下，由 IOTC 外聘僱問整合四國作業層級的漁獲作業資料，估算出最具代表性的鮪延繩釣漁業印度洋大目鮪與黃鰭鮪的單位努力漁獲量標準化序列，提供與 2018 年印度洋鮪類委員會(IOTC)熱帶鮪類工作小組進行印度洋黃鰭鮪魚種資源評估。

本研究根據我國之漁獲資料採用國際合作發展出的研究分析架構以及 R 程式碼進行 CPUE 標準化序列，以利後續之分析比較。根據往年的先期研究對於我國漁業與漁業資料之概況與特性深度剖析，更新定義大目鮪與黃鰭鮪於資源評估用的統計漁區，並利用群集分析法區別出各漁業在各統計區的作業策略，並將此結果作為標的魚種的替代資訊，後續進行大目鮪與黃鰭鮪的 CPUE 標準化時，用群集組別效應納入模式以估算更適當的 CPUE 標準化序列。

本研究亦將觀察員資料與小釣漁業漁獲資料一併進行檢視分析，分析結果顯示我國延繩釣小釣漁業自 2010 後主要作業漁區已與大釣作業漁區高度重疊，但不同的是在東印度洋，如孟加拉灣仍有小釣在此海域捉黃鰭鮪。以小釣作業月別分布趨勢來看，除了 12 月份在偏重東印度洋作業外，其餘月份作業分布較無明顯模式，頗為分散。另分析 2017 年觀察員航次資料，以探討目前統計航次定義(船月)的妥適性，結果顯示原則上以船月為統計航次頗為合理，但是還是有些案例顯示魚種組成周與周之間亦會呈現明顯差異，日後可以嘗試比較以船周為統計航次定義的分析結果是否有顯著差異。

2018 年國際漁業組織 IOTC 更新黃鰭鮪漁獲資料與執行完整資源評估，認為此資源仍面臨過渡捕撈(overfishing)，且達過漁狀態(overfished)。最大持續生產量估計值約 35 萬公噸，而近五年平均每年印度洋黃鰭鮪總漁獲量約 42 萬公噸，而 2017 年約 44 萬公噸。目前黃鰭鮪的國際管理規範似乎並無法有效落實控制漁獲量，後續管理需要再檢討因應。2018 年印度洋大目鮪未做全面性完整評估，根據 2016 年資源評估結果認為此資源尚未面臨過渡捕撈(overfishing)，且未達過漁狀態(overfished)。各種資源評估模式分析結果皆顯示大目鮪目前資源量並未過漁，且亦未處於過漁狀態，然而目前大目鮪最大持續生產量(MSY)點估計為 10 萬四千噸，但是綜合各種資源模式評估結果可能範圍區間分布頗大，約介於 87,000~121,000 噸之間。近五年平均年漁獲量約為十萬公噸，2017 年大目鮪總漁獲量約為九萬公噸，皆未超過 MSY 水準。

三、印度洋熱帶鮪類資源研究(III)：108 年

本計畫主要目標為檢視與分析我國印度洋熱帶鮪類作業層級資料與觀察員資料之漁獲與體 長資料，以掌握漁業利用資源動態發展。配合印度洋鮪類委員會(IOTC)執行印度洋大目鮪與黃鰭鮪魚種資源評估 ，進行印度洋大目鮪與黃鰭鮪 CPUE 標準化研究分析，並提出相關研究報告，以因應 2019 年國際漁業組織印度洋鮪類委員會(IOTC)熱帶鮪類資源指標更新評估。

本研究採用聚集分析處理標的魚種漁獲率的差異性議題，並利用決策樹探討

各聚集所對應之作業策略的特徵。研究發現在熱帶區域，大目鮪、黃鰭鮪、其他魚類(油干)的漁獲量以及作業年代是主要判定聚集分類的因素，解釋度都接近七成。而東熱帶區域，作業策略是隨著不同的作業時期(年代)而有所改變。西熱帶區域的北部則會因緯度的高低，會有不同的作業策略。溫帶水域長鰭鮪、其他魚類(油干)、劍旗魚與南方黑鮪的漁獲量以及作業年代是主要判定聚集分類的因素，解釋度都高過七成。而西溫帶水域，作業策略是隨著不同的作業時期(年代)而有所改變，這個現象呼應了 2006 年油干漁業的發展。東溫帶水域隨著作業時期的改變，會有不同的作業策略，而且有幾艘特定的漁船有其獨特的作業策略。

五年來我國與日本、韓國與塞席爾科學家以及 IOTC 外聘獨立科學家共同探究印度洋熱帶鮪類標準化 CPUE 變動趨勢的合理估算方法，合作過程與成果已於五屆的 IOTC 熱帶鮪類工作小組會議中發表數篇研究報告，有助於印度洋熱帶鮪類資源利用狀態有更清楚的認識。因仍有許多疑慮待釐清，每年的國際合作均受國際漁業管理組織期待。

透過公開透明的國際合作，逐步提升對於漁獲統計資料的深度理解與運用，以期資源評估結果更具確定性。整體而言，除了透過深度的國際合作處理長久以來關於印度洋熱帶鮪類 CPUE 標準化序列趨勢不確定性的議題外，我國持續提供國際漁業組織我國漁業動態資訊對於我國的形象與漁業資源評估的可信度皆有所提升。

參、減輕臺灣魷延繩釣船在東南大西洋作業時海鳥混獲問題的最佳做法

摘要

海鳥兼捕，尤其是信天翁和海燕的兼捕，仍然是遠洋延繩釣漁業中重要的保育議題。本研究評估了三種緩解措施——驅鳥線（BSL）、加重支線和夜間放線——在減少台灣長鰭金槍魚（Thunnus alalunga）延繩釣漁業（作業於東南大西洋）海鳥兼捕方面的有效性。研究人員於 2013 年在一艘商業漁船上進行了 103 次延繩釣作業的觀察。研究測試了四種驅鳥線處理方法：單根和雙根常規驅鳥線，以及國際大西洋鮪魚養護委員會（ICCAT）建議的單根和雙根實驗性驅鳥線，每種處理方法均與加重支線（距鉤 3 米處加重 60 克）或無加重支線結合使用。在放線過程中共捕獲 298 隻海鳥，另有 18 隻海鳥在拖釣和起拖作業過程中被捕獲並放生。夜間設置是最有效的緩解措施，兼捕率為每千鉤 0.046 隻海鳥，遠低於白天設置的每千鉤 1.101 隻海鳥。雖然防鳥網在其有效範圍內能有效阻止海鳥攻擊，但當帶餌的魚鉤超出該範圍，仍處於海鳥的潛水深度時，其效果就會下降。加重支線可將海鳥兼捕率降低 61%；然而，加重支線也可能導致長鰭鮪捕撈率下降。我們的研究結果表明，最佳緩解措施（即防鳥網和加重支線的聯合使用）的有效性取決於確保帶餌的魚鉤在超出防鳥網的有效範圍之前，能夠到達海鳥潛水能力範圍之外的深度。需要進一步優化，以平衡保護效果和漁業績效。

完整版請參閱附件 4

Best practices for mitigating seabird bycatch on Taiwanese albacore longline fishing vessels operating in the southeastern Atlantic Ocean

ABSTRACT

Seabird bycatch—particularly involving albatrosses and petrels—remains a significant conservation concern in pelagic longline fisheries. This study evaluated the effectiveness of three mitigation measures—bird-scaring lines (BSLs), weighted branch lines, and night setting—in reducing seabird bycatch in the Taiwanese albacore (Thunnus alalunga) longline fishery operating in the southeastern Atlantic Ocean. Observations were conducted aboard a commercial vessel during 103 longline sets in 2013. Four BSL treatments were tested: single and double conventional BSLs and single and double experimental BSLs recommended by the International Commission for the Conservation of Atlantic Tunas (ICCAT), each combined with either weighted (60 g at 3 m from the hook) or unweighted branch lines. A total of 298 seabirds were caught during line setting, with an additional 18 birds caught and released alive during hauling and trolling. Night setting emerged as the most effective mitigation measure, with a bycatch rate of 0.046 birds per 1000 hooks—substantially lower than the 1.101 birds per 1000 hooks recorded during daytime setting. While BSLs effectively deterred seabird attacks within their aerial extent, their efficacy declined when baited hooks remained within the diving range of seabirds beyond this zone. Weighted branch lines reduced seabird bycatch by 61 %; however, they were also associated with a potential decrease in albacore catch rates. Our findings highlight that the effectiveness of best practice mitigation—namely, the combined use of BSLs and weighted branch lines—depends on ensuring that baited hooks reach depths beyond seabird diving capabilities before exiting the aerial extent of the BSLs. Further optimization is needed to balance conservation outcomes with fishery performance.

Please see the attachment 4 for the full version.

肆、水下生命相關會議

本校葉裕民教授近十年來，獲行政院能農業委員會漁業署邀請參加十幾次國際會議與發表十幾篇國際會議科學報告。以近期葉裕民教授於 2019 年 4 月 28 日至 5 月 3 日參加「IOTC CPUE 標準化工作小組會議」為例說明之。

本校葉裕民教授參加「IOTC CPUE 標準化工作小組會議」進行專題報告，會議地點在西班牙 AZTI 聖塞巴斯蒂安。會議總結報告重點如下：

參加 IOTC CPUE 標準化工作小組會議

葉裕民教授於 2019 年 4 月 28 日至 5 月 3 日參加「IOTC CPUE 標準化工作小組會議」，進行專題報告，會議地點在西班牙 AZTI 聖塞巴斯蒂安。會議總結報告重點如下：

(一)前言

IOTC CPUE 標準化工作小組會議於本年 4 月 28 日至 5 月 3 日於西班牙 AZTI 聖塞巴斯蒂安舉行，會議主席由 IOTC WPTT 工作小組主席 Dr. Dr. Gorka Merino 擔任，參與人員包括 IOTC 秘書處資源評估專家 Mr. Dan Fu、IOTC 外聘科學家 Dr. Simon Hoyle、日本科學家 Dr. Takayuki Matsumoto，韓國科學家 Dr. Doo Nam Kim、Dr. Sung Il Lee，圍網業者 Dr. Miguel Herrera 以及 IOTC SC 主席 Hilario Murua。而我國代表由南華大學葉裕民副教授和對外漁協資訊組張舒婷組員出席。本次會議主要檢視 Dr. Simon Hoyle 整合台、日、韓以及塞席爾作業層級資料進行大目鮪和黃鰭鮪 CPUE 標準化的結果，該所得結果將提供熱帶鮪類工作小組進行資源評估之用。

(二)會議過程和討論

1.秘書處簡報 IOTC-CPUE 發展歷程及緣由，並說明今年的目標是需要能產出一條整合各國大目鮪 CPUE 標準化供 WPTT 進行大目鮪資源評估，另外亦檢視前兩年 WPTT 及 SC 的建議以提供外聘科學家進行大目鮪 CPUE 標準化，由於部分資源評估模型設定中無法同時納入分區 CPUE 序列，因此需要將分區 CPUE 序列整合為一條，外聘科學家表示對於如何整合 CPUE 序列方式可能要進行區域權重估計研究。

2.日本代表簡報其大目鮪與黃鰭鮪漁業發展及說明歷年漁獲量分布和CPUE趨勢狀態，其中日本說明雖然近年東南印度洋長鰭鮪漁獲量呈現增加趨勢，但體型皆不大，應非屬專作性質，這可能與作業船漁撈策略轉變有關，而因日本於熱帶區域作業的每筐鈎數(HBF)在超過 22 鈎的比例明顯增加，與我國近年因使用美式滾筒作業而導致 HBF 大幅增加的情況類似，故會中有詢問是否亦因美式滾筒作業影響，但其表示，尚未聽過美式滾筒導入作業中，其只聽說近期業者在支繩設置上改採較輕的材質，但不清楚之間是否有相關，

另外會中討論日本早期努力量變動成因很大因素與石油危機相關。而在檢視日本 CPUE 趨勢中發現，在模型中的主支繩材質與 HBF 的相關性很高(可能是因當材質改變，為了維持一樣的漁獲力，通常 HBF 亦會進行調整)，對於 HBF 的解釋力可能造成混淆。

3.韓國代表簡報其大目鮪與黃鰭鮪漁業發展及說明歷年漁獲量分布和 CPUE 趨勢狀態，其說明今年度漁場主要都在熱帶區域，主因是作業船未前往澳洲西岸作業南方黑鮪，另黃鰭鮪漁獲量在馬達加斯加西岸呈現增加趨勢，整體看來，近兩年漁獲分布主要是在馬達加斯加跟熱帶海域。而在 HBF 分佈上，明顯呈現兩種峰度(深鉤 15 鉤與淺鉤 10 鉤)，主要與其漁船作業動態相關，通常部分船會季節性南下溫帶區域漁撈南方黑鮪，待漁季結束後再重返熱帶區域作業，但亦會有部分船則是全年在熱帶區域漁撈大目鮪與黃鰭鮪.

4.外聘科學家 Dr. Simon Hoyle 說明現階段大目鮪和黃鰭鮪區域劃分方式及不分區的方式，並討論分區 CPUE 該如何合併估計一條全印度洋的 CPUE 指標序列，可提供其他資源評估模式使用，會中提到依據 cluster 比重方式會是一個可行的方向。

5.葉裕民副教授簡報我國大目鮪與黃鰭鮪漁業發展及說明歷年漁獲量分布和 CPUE 趨勢狀態，並於會中反應我國業者針對黃鰭鮪和大目鮪資源評估結果與實際漁況不相符的情形，而日本韓國代表表示其黃鰭鮪漁獲目前皆無法達到配額量，故無配額不敷使用的問題，且亦未聽聞業者表達黃鰭鮪漁況佳的情形，但這亦有可能是因與台灣作業區域不同所致，對此會中討論若因漁況佳導致配額不敷使用，則應會在丟棄量反應出來，應先對丟棄量情況先行檢視，故請各方代表整理歷年大目鮪和黃鰭鮪丟棄量趨勢圖及比例圖後在一同檢視，另外亦針對是否應將我方小釣作業層級資料投入 CPUE 標準化中進行討論，外聘科學家表示由於作業型態不同，並不適宜併入大釣船資料中進行運算，但可先行檢視小釣船作業層級資料的分布了解其影響性，並詢問我方是否能提供進行檢視，我方回應該資料尚未授權提供與會使用，會在詢問是否可釋出。

6.圍網業者代表 Dr.Miguel Herrera 簡報探究延繩釣體長樣本誤報對於資源評估結果的潛在影響性，主要檢視各延繩釣國各年代之各項體長頻度資料(logbook 或觀察員資料)，強調無小型魚的體長分布極有可能因丟棄行為所造成，尤其自 2002 年開始台灣與塞昔爾明顯皆無小型魚體長分布，顯見小型魚漁獲量可能因丟棄而未反應在總漁獲量上，故認為進行 CPUE 標準化時應將丟棄因素加入考量才不會造成整體資源評估的偏誤。我方表示台灣小型魚體長比例自 2002 年開始急遽下降，可能與當時陸續有回籍船歸籍有關，因該等船皆是屬熱帶鮪類專作船，故漁獲體型皆偏大，若再加上船長未隨機進行量測，則就可能造成大型魚比例突然急增的情形，且小型魚亦是有其市場價值，部份作業船會趁進國外港口補給時，順便卸往當地市場，而並非只會丟棄，而韓國、日本代表皆回應該國黃鰭鮪漁獲量皆未達配額標準或者大

目鮪並無配額管制，故作業船丟棄行為是極少發生，而目前日本韓國雖皆有丟棄量資訊的收集，但丟棄量回報很少，對此 Dr.Miguel Herrera 認為，因作業船魚艙有限，只要漁獲非該船之目標魚種者皆可能造成船長丟棄行為，並非全是因為配額管制所造成。

7.葉裕民副教授說明 2002-2018 年大目鮪與黃鰭鮪丟棄量比例情形，並指出黃鰭鮪丟棄量比例確實在 IOTC 採取配額管制後明顯增加，而大目鮪丟棄量比例則並無太大變化，而會中討論 logbook 涵蓋率雖然是百分之百，但依據目前台灣、日本和韓國的丟棄量回報比例都極低的情形下，其未必能真實代表實際丟棄量情形，而為了解我方作業船回報丟棄的船數比例及鉤數比例，會中亦請我方再行估算歷年回報丟棄的船數比例及鉤數比例。

8.日本簡報黃鰭鮪跟大目鮪 CPUE 標準化之結果，主要依據外聘科學家 Dr.Simon Hoyle 更新的 R code，並加入 2018 年資料之運行結果，而會中主要討論每 HBF 對於日本 CPUE 標準化模式的影響性及相關性，以及模式中是否採用 veesels_id 對於 CPUE 標準化趨勢產生的變化。

9.韓國簡報黃鰭鮪 CPUE 標準化之結果，主要依據外聘科學家 Dr.Simon Hoyle 更新的 R code，並加入 2018 年資料之運行結果，而會中討論近年韓國作業船因海盜問題並非都有持續在熱帶區域作業，導致 CPUE 標準化趨勢序列於部分年份有中斷情形，另外亦討論在每鉤數的變化上，近年亦呈現增加的趨勢。

10.葉裕民老師簡報黃鰭鮪跟大目鮪 CPUE 標準化之結果，主要依據外聘科學家 Dr.Simon Hoyle 更新的 R code，並加入 2018 年資料之運行結果，由於台灣 CPUE 序列模型中所放入的 cluster 因子似乎無法明確定義目標魚種，可能後續對於年效應的 CPUE 趨勢產生影響，故會中亦討論是否放入 cluster 因子對於 CPUE 序列的影響程度，並請我方亦再行估算在模型中放入幾組不同因子組合的 CPUE 序列，主要在是否採用 cluster 因子或 HBF 因子，模式之因子組合如下:

(1)長時間序列(1979~2018) without cluster factor included in std model.

(2)長時間序列(1979~2001, 2015~2018) without cluster factor included in std model.

(3)長時間序列(1979~2001, 2015~2018) with cluster factor included in std model.

(4)短時間序列(1995~2018) with cluster factor included in std model.

(5)短時間序列(1995~2018) with HBF factor included in std model.

而後續亦將日本、韓國及台灣各運算之 CPUE 序列結果整合一起進行檢視，結果顯示三國各自之 CPUE 序列趨勢並不一致，且其差異性並無法解釋。

11.本次由外聘科學家 Dr. Simon Hoyle 進行大目鮪和黃鰭鮪聯合 CPUE 標準化模式評估，主要的資料架構有 1952-2018 年日本資料、1971-2017 年韓國資

料、2005-2018 年台灣資料及 2000-2017 年塞昔爾資料，而因塞昔爾序列資料缺漏 HBF，故若模型中有使用 HBF 作為因子則就不會納入該國資料進行分析，另由於日本序列資料，早期缺漏 vessel ID，小組建議亦將該情形納入考量，故建議大目鮪和黃鰭鮪之 CPUE 標準化模型亦應分期進行架構，包括 1952-2018 年模型未納入 vessel ID 和 1952-1978 年模型未納入 vessel ID 但 1979-2018 年模型納入 vessel ID，並同時檢視 cluster 因子和 HBF 因子放入模型中的解釋力，以及台灣提供之兩種定義之丟棄率所進行的模型校正，但整體 CPUE 趨勢皆無明顯差異，故會中討論到 cluster 因子在區別熱帶與溫帶作業時之解釋力較高，但若只在熱帶區域則解釋力相對較低，因此建議未來可考量將大目鮪與黃鰭鮪漁獲合併進行 cluster 因子分析，以提供 cluster 因子在模型中的解釋力。

12. 由於外聘科學家 Dr. Simon Hoyle 與 IOTC 秘書處協定需對各國科學家進行 CPUE 標準化程式碼之教育訓練，故本次會中亦安排外聘科學家 Dr. Simon Hoyle 說明其進行聯合 CPUE 標準化所運算之 R 程式碼架構，而目前所運算之 R 程式碼及其套件皆是存放在雲端供各國科學家下載運算。

(三)檢討與建議事項

1. 近年我國延繩釣業者一直對於 IOTC 大目鮪與黃鰭鮪資源評估結果與現況不符產生質疑，而本次參與會議之圍網業者代表亦透露出相同的質疑，並認為資源評估模型中之 CPUE 序列可能因忽略丟棄量而導致評估結果出現偏誤，尤其在進行漁獲量管制後，丟棄量的影響必定提高。而這也開始促始 IOTC 關注延繩釣船丟棄量的議題，本次聯合 CPUE 分析已開始將丟棄量納入模型中進行校正，故後續需持續關注是否將對先前資源評估結果進行修正，尤其是在黃鰭鮪的資源評估上。
2. 2017-2018 年我國黃鰭鮪丟棄量比例相較歷年明顯上升，但我國整體大目鮪與黃鰭鮪丟棄量比例仍是處於偏低狀態，雖然目前 IOTC 尚未要求我國提交丟棄量資料，但現階段已開始嘗試將丟棄量納入 CPUE 標準化分析中，因此未來對於丟棄量資料收集將顯得重要，建議後續應加強對業者宣傳丟棄量回報之重要性，以期提升我國丟棄量回報之比例。
3. 本次會議已開始關注我國小釣作業層級資料，認為該資料若能發展 CPUE 序列並一同納入資源評估模型中，將有助於整體資源評估的結果，故後續對於小釣作業層級資料應先行檢視可利用性，以便因應屆時 CPUE 工作小組提出該資料之需求。

附件 1

印度洋熱帶鮪類資源研究(106 年度)

行政院農業委員會 106 年度科技計畫期末研究報告
計畫名稱：印度洋熱帶鮪類資源研究
CPUE index and stock assessment of Taiwanese tropical tunas in the Indian Ocean
計畫主持人：南華大學葉裕民 副教授
計畫編號：106 農科-9.1.2-漁-F2(2)
全程計畫期間：106 年 1 月 1 日至 106 年 12 月 31 日

中文摘要

依本年度全程計畫目標檢視與分析我國印度洋熱帶鮪類作業層級資料與觀察員資料之漁獲與體長資料，以掌握漁業利用資源動態發展。並進行印度洋大目鮪與黃鰭鮪 CPUE 標準化研究分析，以因應 2017 年國際漁業組織印度洋鮪類委員會(IOTC)熱帶鮪類資源指標更新評估。

根據觀察員資料進行印度洋大目鮪與黃鰭鮪體長與體重關係式估算，印度洋大目鮪體長與體重關係式估算為 $\boldsymbol{W_i = 0.0000214L_i^{2.98211}}$，印度洋黃鰭鮪體長與體重關係式估算為 $\boldsymbol{W_i = 0.00059L_i^{2.794842}}$。

今年四度進行延續性進階國際合作，在台日韓與塞席爾四國作業日誌資料的保密性已充分考慮下，由 IOTC 外聘僱問整合四國作業層級的漁獲作業資料，估算出最具代表性的鮪延繩釣漁業印度洋大目鮪與黃鰭鮪的單位努力漁獲量標準化序列，提供與 2016 年印度洋鮪類委員會(IOTC)熱帶鮪類工作小組進行印度洋大目鮪與黃鰭鮪魚種資源評估。

本研究根據我國之漁獲資料採用國際合作發展出的研究分析架構以及 R 程式碼進行 CPUE 標準化序列，以利後續之分析比較。根據往年的先期研究對於我國漁業與漁業資料之概況與特性深度剖析，更新定義大目鮪與黃鰭鮪於資源評估用的統計漁區，並利用群集分析法區別出各漁業在各統計區的作業策略，並將此結果作為標的魚種的替代資訊，後續進行大目鮪與黃鰭鮪的 CPUE 標準化時，可以用群集組別效應納入模式以估算更適當的 CPUE 標準化序列。

經由四年的國際合作研究，依據分析結果，形成許多觀點與建議可供後續在資料處理與研究方向上參考。整體而言，透過深度的國際合作處理，長久以來關於印度洋熱帶鮪類 CPUE 標準化序列趨勢不確定性的緊張情勢已在今年的資源評估工作上已大幅緩解。漁業署已與 IOTC 及其他會員國達成共識，支持此一國際合作計畫，相信對於我國的形象與漁業資源評估的可信度皆有所提升。

英文摘要(Abstract)

The goals of the project include the analysis of Taiwanese tuna longline logbook data and observer data in the Indian Ocean and the standardization of CPUE series. In order to investigate the issue of the discrepancy between Taiwanese and Japanese CPUE series for Indian bigeye and yellowfin tuna, the project will focus on the analysis of the fishing selectivity for the Taiwanese tuna longline fisheries in the Indian Ocean.

At the current moment, the relationship between length and weight for Indian bigeye and yellowfin based on our Taiwanese observer data were estimated. The estimated model for Indian bigeye is $\boldsymbol{W_i = 0.0000214 L_i^{2.98211}}$ and $\boldsymbol{W_i = 0.0000459 L_i^{2.794842}}$ is for Indian yellowfin.

Updated Taiwanese longline fishery data to 1979-2016 were used in this analysis. We used cluster analysis to classify longline sets into groups based on the species composition of the catch, to understand whether cluster analysis could identify distinct fishing strategies. Bigeye and yellowfin tuna CPUE were then standardized. All analyses were based on the approaches used by the collaborative workshop of longline data and CPUE standardization for bigeye and yellowfin tuna held in June 2017 in Taipei and in July 2017 in Busan.

The continuous collaborative study was conducted between national scientists with expertise in Japanese, Taiwanese, Korean and Seychelles longline fleets, and an independent scientist this year. The workshop addressed Terms of Reference covering several important and longstanding issues related to the bigeye and yellowfin tuna CPUE indices in the Indian Ocean, based on data from the Japanese and Taiwanese fleets. Data from the Korean and Seychelles longline fleet were also considered, as a valuable source of independent information.

Base on the similar analysis framework developed in the joint workshop, this study categorized various fishing strategies for Taiwanese longline fishery in the Indian Ocean by cluster analysis. And the study used the outcome of cluster analysis in the GLM to standardize the CPUE series to consider the target issue. The result of this study was applied the relevant information to facilitate IOTC to fulfil the management of Indian tropical tuna.

第一章　前言

印度洋熱帶鮪類大目鮪與黃鰭鮪是台灣鮪延繩釣漁業在印度洋主要利用的經濟魚種。台灣鮪延繩釣漁業亦是印度洋大目鮪與黃鰭鮪魚種的主要傳統利用漁業之一，因此印度洋大目鮪與黃鰭鮪魚種資源評估工作均仰賴我國提供標準化單位努力漁獲量做為資源量變動之參考指標。我國進行標準化單位努力漁獲量時間變動趨勢的估計是根據我國印度洋鮪延繩船隊漁業活動之漁獲作業日誌資料。然漁獲作業日誌回收率於 2000 年前年間變化較大，2000 年後每年漁獲作業日誌回收率則趨於穩定，且近年皆高於八成。比較歷年漁獲作業日誌所顯示我國在印度洋的鮪延繩船隊的漁業活動分布，雖然某些年漁獲作業日誌回收率較低，但仍相當程度反映了我國漁業在印度洋作業的特性。

另因 2002-2004 年我國大西洋與印度洋之間發生的洗魚事件，檢視這三年漁獲作業日誌，整體船隊普遍漁獲表現異常，且根據現有資料無法進行有效辨別個別船隻填報可信賴度，為確保我國 CPUE 標準化序列的適當性，因此去年相關研究進行印度洋大目鮪與黃鰭鮪魚種標準化單位努力漁獲量時間序列的估計採用之資料年限雖為 1979 年至 2015 年，但剔除 2002-2004 年的資料，分析結果提供與 2016 年印度洋鮪類委員會(IOTC)熱帶鮪類工作小組進行印度洋大目鮪與黃鰭鮪魚種資源評估。

因分析台灣印度洋鮪延繩釣漁業標的魚種黃鰭鮪與大目鮪的漁獲率時，若只考慮作業漁季、作業漁區以及漁獲組成等因子，而不考慮作業之標的魚種的移轉，並無法台灣印度洋鮪延繩釣船隊對於印度洋黃鰭鮪及大目鮪漁獲能力的變異進行適當的掌握。 因此相關研究利用聚集分析方法，根據每次作業或航次（船月別）漁獲組成的相似性進行分類，鑑別每次作業或航次的標的魚種，進而將組別視作為一目標魚種(或作業策略)的有效漁撈能力。

關於遠洋鮪延繩釣漁業或船隊之漁撈能力 (fishing power) 一直是目前認為標準化 CPUE 序列趨勢若要用來作為資源量變動指標是必要可慮的議題。我國印度洋鮪延繩釣漁船大目鮪漁撈能力在核心區域從 1979 年的 0.9 些微增加至 2012 年的 1.1。 特別的是在南印度洋海域在 1979 年至 2012 年年間從 0.7 明顯增至 1.4。 我國印度洋鮪延繩釣漁船黃鰭鮪漁撈能力在核心區域從 1979 年的 0.7 些微增加至 1993 年的 1.0，之後幾乎皆維持在穩定的水準。 而在南印度洋海域在 1979 年以及 1989 年有較高的漁撈能力 1.2，在 1992 年以及 1993 年有較低的漁撈能力 0.6 外，其他年度至 1996 年都約為 1.0，自 1996 年後則持續增加至 2012 年的 1.3 年。整體而言，我國印度洋鮪延繩釣漁船大目鮪與黃鰭鮪漁撈能力並不如預期得和日本一樣呈現明顯上升趨勢。因此目前我國漁撈能力變異的機制尚無法掌握。

印度洋黃鰭鮪及大目鮪的資源狀態一直是國際漁業組織 IOTC 關注的事項。印度洋熱帶鮪類的資源評估工作非常倚賴臺灣與日本的 CPUE 標準化序列指標。然而若視臺灣與日本的 CPUE 標準化序列皆為資源變動的指標，如何解釋彼此指標的變動關係及與資源量的相互關係一直是被探討的議題。

在印度洋，台灣和日本鮪延繩釣船隊的作業型態，長年來包括標的魚種的移轉，作業空間的分布各有其歷史變革。以近幾年來看，台灣一直以大目鮪為標的魚種，而日本則以黃鰭鮪為標的魚種。且台灣的作業分布遍及印度洋大部分海域，而日本作業分布較為侷限，百分之七十的黃鰭鮪漁獲量是來自於莫三比克海峽附近海域，所以若目前大目鮪與黃鰭鮪資源評估只用日本的資料，會有代表性的問

題。

然而 1980 年後，依據台灣漁獲日誌資料所獲得之印度洋黃鰭鮪與大目鮪的 CPUE 標準化序列趨勢與日本的序列趨勢並不一致。兩年前透過 IOTC、IOTC 外聘科學顧問以及台日韓三國國際合作研究，整合台日韓三國作業層級資料，估算整合性 CPUE 標準化序列以作為最佳資源變動的指標。根據現階段合作結果認為，差異性主要源自於原始資料(名目漁獲努力量，Nominal CPUE)的本質，而非資料處理或研究方法的變異。我國船隊作業日誌回收率年間變化頗大，從 1979 年約 63%，到 1992 年，回收率最低，只有 4%。 整體而言，1984 年到 2002 年回收率在五成以下，因過低的回收率可能會降低作業日誌反映整個船隊作業概況的代表性。

且檢視台日韓三國在印度洋赤道海域年別每次作業大目鮪漁獲尾數的頻度分佈圖，在 1977~2001 年以及 2005~2008 年年間，三國的分佈頗為相似。但在 1983~1991 年低漁獲(如每次作業捕獲 20 尾大目鮪)各國的變動幅度較大且不甚一致外，其中 2002~2004 年台灣的分佈模式異常，且和他國相比，平均而言，每次作業大目鮪漁獲尾數高出許多。 然而這三年台灣作業分佈似乎無明顯變化，推測此和 2002-2004 年我國大西洋與印度洋之間發生的洗魚事件有關，因此估算整合性 CPUE 標準化序列時，只取我國 2005 年(含)之後的作業日誌資料。

目前大目鮪與黃鰭鮪資源評估雖採用的延繩釣整合性 CPUE 標準化序列，然未來各國仍須分別提供各國之 CPUE 標準化序列以綜合分析比較，因此台灣與日本序列趨勢不一致的議題仍須繼續探究。

為理解台灣與日本序列趨勢不一致的可能原因，已嘗試由歷年兩國標的魚種的移轉與作業漁區的重疊性等面向探討。關於兩國延繩釣漁業的漁業選擇係數(Selectivity)是否有差異尚未深究。因此探討的重點會針對我國漁業利用聚集分析，根據每次航次漁獲組成的相似性進行分類所鑑別出之各種作業策略做更深入的分析。檢視分析各作業策略所捕獲之大目鮪與黃鰭鮪體長分布特性。但台灣熱帶鮪類漁獲體長資料 1997 年之後填報之魚體呈現系統係偏差，經對外漁業合作協會詳加檢視，發現部分船隻的填報行為異常，如填報之魚體體長和體重常成一線性關係，也是疑將體重加一固定數最為體長之填報值。因此本研究進行體長相關研究，擬採用累計多年的觀察員資料進行分析。

因此今年度計畫目標即為檢視與分析我國印度洋熱帶鮪類作業層級資料與觀察員資料之漁獲與體長資料，以掌握漁業利用資源動態發展。並進行印度洋大目鮪與黃鰭鮪 CPUE 標準化研究分析，以因應 2017 年國際漁業組織印度洋鮪類委員會(IOTC)熱帶鮪類資源指標更新評估。

第二章　實施方法

印度洋鮪延繩釣漁業電子作業日誌(E-logbook)從 2013 年開始推行，2014 年與紙本作業日誌並行，因為許多船仍在海上作業無法回台安裝相關軟硬體設備，但於 2015 年已全面實施，回收率約八成，2016 年回收率已達百分之百。

對外漁協於會期間，初步檢視一艘船同時繳交紙本與電子作業日誌時，漁獲內容的一致性，雖然差異性仍存在於不同欄位內，但整體看來，大部分的資料吻合度頗高。所以對外漁協提供給 IOTC 所對應的作業日誌資料於 2015 年後即是以電子作業日誌為依據。今年七月印度洋熱帶鮪類的國際合作(也就是第四屆 CPUE 工作小組會議)是在韓國釜山舉辦，主要合作內容即針對熱帶鮪類(大目鮪與黃鰭鮪) CPUE 進行標準化與教育訓練。資料更新增補的部分是 2016 年的資料。

根據對外漁協提供的觀察員資料進行印度洋大目鮪與黃鰭鮪體長與體重關係分析。歷年觀察員資料填報格式多有變革，故 2002 年至 2015 年(部分)的資料分別共有六個 Access 資料庫。Access 資料庫含各式資料表，如「延繩釣作業記錄表」、「延繩釣航次」、「漁船漁獲內容紀錄」、「觀測時段漁獲物上鉤紀錄」等。

體長與體重關係分析研究，基本上需要延繩釣作業紀錄表識別碼、魚種代碼、處理代碼、量測代碼、長度(公分)、重量(公斤) 、性別、航程代碼、作業紀錄日期、下鉤開始日期、下鉤開始南北、下鉤開始緯度、下鉤開始東西、下鉤開始經度、漁船識別碼、洋區、組別、離港日期、進港日期、漁船總長度(公尺)、漁船總噸位(公噸) 與漁船馬力(匹)。但是有些年度欄位紀錄不全，所以需要進一步處理。

資料處理分為以下步驟：

1. 因 2002 年至 2003 年無處理代碼記錄，故假定皆為常用處理熱帶鮪類的方式，留艙、去鰓、去尾與去內臟的處理方式，即所謂的 RGG。
2. 須針對不同處理後的重量近行全魚重的轉換。因我國目前相關研究，只有 RGG 的轉換係數(1.16)，故另亦常見於處理熱帶鮪類的留艙、去頭與去內臟(RHG)的轉換係數，以 IOTC 的 HDD (Dressed carcasses with heads off and fins off and tail present) 1.43 替代(表 5)。
3. 資料除錯是視體長大於 500 公分，體重大於 200 公斤為異常值而剔除。體長與體重缺失值的紀錄亦無法納入分析。

2.1　台灣作業層級資料與漁業概況分析

以對外漁協（OFDC）提供之 1979 年至 2016 年臺灣印度洋鮪延繩釣漁船之一度方格漁獲日誌資料以及觀察員資料作為分析依據。針對我國遠洋鮪延繩釣漁獲統計資料庫之漁獲努力量與各魚種漁獲量時間與空間分佈等項目資料進行深度檢視，以掌握漁業歷年發展動態。

大釣的作業船隻登記有三種作業組別，分別是大目鮪組(target bigeye)，長鰭鮪組與兼營組(target bigeye and albacore)。觀察員資料(2002~2016)則有五種作業組別，除上述三種外，另有黃鰭鮪組與南方黑鮪組。因只有少數船隻在部分年度 target yellowfin，非為一般作業型態，所以一般 logbook 沒有此類組別紀錄。另船隻必須特別申請執照才能去補獲南方黑鮪，亦非常態登記組別，所以一般 logbook

亦沒有此類組別紀錄。

2.2 印度洋大目鮪與黃鰭鮪體長與體重關係式估算

利用統計軟體 R 的套件 FSA 全魚重 FL 尾叉長

$$\boldsymbol{W_i = aL_i^b e^{\epsilon_i}}$$

$$\mathbf{log}(\boldsymbol{W_i}) = \mathbf{log}(\boldsymbol{a}) + \boldsymbol{blog}(\boldsymbol{L_i}) + \boldsymbol{\epsilon_i}$$

2.3 聚集分析(Cluster Analysis)

因分析台灣印度洋鮪延繩釣漁業標的魚種黃鰭鮪與大目鮪的漁獲率時，若只考慮作業漁季、作業漁區以及漁獲組成等因子，而不考慮作業之標的魚種的移轉，並無法對於印度洋黃鰭鮪及大目鮪漁獲率的變異進行適當的掌握。因此本研究利用聚集分析，根據每次作業或航次（船月別）漁獲組成的相似性進行分類，期能鑑別每次作業或航次的標的魚種，進而將組別視作為一目標魚種(或作業策略)的替代指標。考慮以航次別作為一分析單位是因縱使標的魚種不變，時空變異之下，其漁獲組成的比例仍存有異質性。 因此預計以航次資料為一分析單位，進而設計分析架構，滿足組別內的變異程度小於組別間的變異，使聚集分析結果更具確適性。

因此考慮每次作業的魚種漁獲，包括黃鰭鮪、大目鮪、長鰭鮪、黑鮪、南方黑鮪、劍旗魚、旗魚類(黑皮旗魚、白皮旗魚、紅肉旗魚)、鯊魚以及其他魚類的漁獲組成。

此研究採用的方法主要參考 Bigelow and Hoyle(2012)以及 Winker *et al.* (2014)的研究方法。首先去除無任何漁獲的作業紀錄，計算每筆作業紀錄各魚種漁獲尾數佔總漁獲尾數的百分比。採用兩種資料處理方式進行聚集分析，第一種方式是將漁獲組成資料進行轉換以避免某些平均漁獲量較大的魚種會影響分析的有效性。轉換方式即是標準化常態分佈的過程。而另一種方式即是不作任何資料轉換。

根據以往採用三種聚集分析方法的經驗，此次選用為 Ward hclust。階層式聚集分析(hierarchical cluster analysis, Ward method)乃先利用統計分析軟體 R 的 dist 函數功能計算資料結構異質性的距離，然後再用 hclust 函數功能，給定參數 Ward.D 進行分析。

一般而言，聚集組別的選定頗為主觀。本研究根據漁業實況，判定至少會有兩種不同作業策略存在於船隊中，一是以大目鮪為標的魚種，二是以長鰭鮪為標的魚種。 組別選定會參考不同的統計分析結果。用聚集分析鑑別出的群組則可視做不同的漁業策略或標的魚種，然後擷取主要集群放入模式分析，進行 CPUE 標準化。

2.4 泛線性模式（Constant lognormal Generalized Linear Model, GLM）與 Delta-Lognormal GLM

根據 1979 年至 2016 年臺灣鮪延繩釣漁業資料作業層級資料，利用兩種泛線性模式估計台灣鮪延繩釣漁業利用印度洋大目鮪與黃鰭鮪單位努力漁獲量標準化變動趨勢。Constant lognormal GLM 主要用在探索各因子對於 CPUE 序列趨勢的解釋力與影響力(Bentley *et al.*, 2012)。Delta-Lognormal GLM 適用在標準化 CPUE 序列，以下分述之。

分別針對大目鮪與黃鰭鮪區依同質性原則，將印度洋劃分成數個統計漁區，大目鮪與黃鰭鮪分區定義請見圖 x。分魚種分區分別進行單位努力漁獲量標準化研究，利用泛線性模式估計台灣鮪延繩釣漁業利用印度洋大目鮪與黃鰭鮪單位努

力漁獲量標準化變動趨勢部分採用的基本模式是以時間(年季)(yrqtr)、五度方格空間(latlong)、漁船(vessid)以及作業策略(標的魚種)組別(hcltrp)為主要因子。

<u>Constant Lognormal GLM：</u>

CPUE+mn ~ yrqtr + latlong + vessid + hcltrp + ns(hooks,df=11) +ε

<u>Delta-Lognormal GLM：</u>

$$\Pr(Y=y)=\begin{cases} \boldsymbol{w}, & \boldsymbol{y=0} \\ (\boldsymbol{1-w})\boldsymbol{f}(\boldsymbol{y}) & \boldsymbol{otherwise} \end{cases}$$

g(w) = (CPUE = 0) ~ yrqtr + vessid + latlong + hcltrp + ns(hooks,df=11)+ε, where g is the logistic function.

f(y) = CPUE ~ yrqtr + vessid + latlong + hcltrp + ns(hooks,df=11) +ε.

並進一步分析模式殘差分佈，以了解模式套適效果，估計最適資源量變動指標。並配合提供印度洋鮪類委員會(IOTC)執行大目鮪與黃鰭鮪資源評估，提出相關研究報告。

第三章　結果與討論

3.1　印度洋大目鮪與黃鰭鮪研究文獻回顧

回顧印度洋大目鮪與黃鰭鮪體長與體重關係式估算分析，全印度洋洋區不分性別大目鮪體長與體重關係式估算為 $\boldsymbol{W_i = 0.00002.396L_i^{2.951}}$，全印度洋洋區不分性別印度洋黃鰭鮪體長與體重關係式估算為 $\boldsymbol{W_i = 0.000015849L_i^{3.046}}$。

3.2　印度洋大目鮪與黃鰭鮪資源狀況與各國漁業利用概況

近五年平均每年印度洋大目鮪總漁獲量約 10 萬兩千公噸，而 2015 年約 9 萬三千公噸。近五年平均每年印度洋黃鰭鮪總漁獲量約 39 萬公噸，而 2015 年約 41 萬公噸。2016 年印度洋大目鮪的資源評估結果認為此資源尚未面臨過渡捕撈(overfishing)，且未達過漁狀態(overfished)。各種資源評估模式分析結果皆顯示大目鮪目前資源量並未過漁(not overfished)，且亦未處於過漁狀態(not overfishing)，然而目前大目鮪最大持續生產量(MSY)點估計為 10 萬四千噸，但是綜合各種資源模式評估結果可能範圍區間分布頗大，約介於 87,000~121,000 噸之間，且持續建議大目鮪漁獲量不應超過 MSY 水準，若在努力量持續下降，且漁獲量持續低於 MSY 水準下，則就不需要有立即性的管理措施，但仍需加強對於資料收集及分析，以降低評估的不確定性。

今年僅應用更新資料進行黃鰭鮪資源評估，資源狀況仍處於紅字警戒，雖然機率已從前年的 94%降至目前的 68%，然此資源仍面臨過渡捕撈(overfishing)，且達過漁狀態(overfished)。最大持續生產量估計值約 42 萬公噸，近五年平均每年印度洋黃鰭鮪總漁獲量約 39 萬公噸，而 2015 年約 40 萬公噸。2017 年已有管理措施即將施行，我國印度洋鮪延繩釣漁業的漁獲量必須管控在 2014 年漁獲水準的 90%。

比較歷年漁獲作業日誌所顯示我國在印度洋的鮪延繩船隊的漁業活動分布，雖然某些年漁獲作業日誌回收率較低，但仍相當程度反映了我國漁業在印度洋作業的特性。檢視這三年漁獲作業日誌檢視我國 2014 年與 2015 年在印度洋漁區年別漁獲組成漁獲量、漁獲努力量(鉤數)大目鮪與黃鰭鮪名目單位努力漁獲量空間分布概況，與前兩年概況並無顯著差異。

台灣熱帶鮪類漁獲體長資料 1997 年之後填報之魚體呈現系統係偏差，經對外漁業合作協會詳加檢視，發現部分船隻的填報行為異常，如填報之魚體體長和體重常成一線性關係，也是疑將體重加一固定數最為體長之填報值(圖)。因此建議日後若需進行體長相關研究，宜採用觀察員資料進行分析。

3.3　印度洋大目鮪與黃鰭鮪體長與體重關係式估算

圖 15 顯示 2002 年至 2015 年觀察員觀測大目鮪與黃鰭鮪之體長與體重資料頻度分布圖。大目鮪體長分布為 50 公分至 200 公分，體重分布為 1 公斤至 140 公斤。黃鰭鮪體長分布為 10 公分至 180 公分，體重分布為 1 公斤至 100 公斤。

印度洋大目鮪體長與體重關係式估算為

$$\boldsymbol{W_i = 0.0000214L_i^{2.98211}}$$

印度洋黃鰭鮪體長與體重關係式估算為

$$\boldsymbol{W_i = 0.0000459L_i^{2.794842}}$$

2002 年至 2015 年觀察員觀測大目鮪與黃鰭鮪對數尺度與原始尺度的體長體重關係式(圖 16)。 2002 年至 2015 年觀察員觀測大目鮪與黃鰭鮪體長體重關係式模式估計套適殘差分佈圖與 QQPLOT(圖 17)。

3.4 各作業策略對應之體長分布

體長資料的資訊提供對於 cpue 的代表性更多的理解。今年已應用 Simon 的 R scrips 初步完成兩種魚種 cpue 標準化。並初步檢視各作業組別以及各區域各群集 (clusters)之觀察員紀錄體長資料分布特性。進一步檢視觀察員體長資料時空分布特徵。

3.5 聚集分析結果

表 11 與表 12 顯示分別依據大目鮪與黃鰭鮪漁區定義，各區域聚集分析方法的結果。以大目鮪區域 1N 為例，方法 hcltrip 結果清楚顯示聚集一，主要目標魚種為大目鮪與黃鰭鮪，次要魚種為劍旗魚；聚集二，主要目標魚種包括大目鮪、次之為黃鰭鮪；聚集三，主要目標魚種大目鮪與劍旗魚，次之為黃鰭鮪；聚集四，主要目標魚種包括黃鰭鮪，次之為大目鮪；聚集五，主要目標魚種包括大目鮪，次之為其他魚種，黃鰭鮪以及劍旗魚也佔一定的比例。圖 24 至圖 43 呈現各區域內各聚集作業特性、作業空間分佈以及漁獲組成特性，各聚集的作業空間分佈相對於其他特徵呈現比較明顯的區隔。

以大目鮪漁區區域 1N 聚集分析為例(圖 22)，各類統計分析結果顯示將作業資料分成五個聚集群組為最佳。而圖 30 顯示以大目鮪漁區區域 3 為例，各聚集群組內的作業特徵。如第四類聚集群組應對應的是自 2005 年後以油魚為標的魚種的作業紀錄，而第一類聚集群組則對應的是以長鰭鮪為標的魚種的作業紀錄，而第二類聚集群組則對應的是以大目鮪、黃鰭鮪與劍旗魚為標的魚種的作業紀錄。我國作業日誌已經從 2009 後有獨立紀錄油魚漁獲，本研究根據此資訊可確認聚集分析在缺乏獨立油魚漁獲紀錄的往年，仍可以根據漁獲組成以聚集分析成功隔離出油魚漁業，並將此類作業努力量剔除於熱帶鮪類 CPUE 標準化的分析研究。

3.6 CPUE 結果

根據 Constant Lognormal GLM 的分析結果，表 13 至表 21 與圖 44 至圖 52 呈現各區域大目鮪與黃鰭鮪 CPUE 標準化模式，各因子對於 CPUE 序列趨勢的解釋力與影響力之統計分析表。簡單來說，由影響力分析可以了解名目 CPUE 序列與標準化 CPUE 序列的差異主要是來自於哪一個主要因子的影響。 隨然某個因子可以解釋很大的 CPUE 值的變異，但是加入此因子並不一定會有明顯的校正效果。原因是可能每年這個因子的實際變數值分布會很類似，舉例來說，季節或許可以解釋很大程度 CPUE 的變異，然每年作業努力量在各季節的作業分布可能很類似，因此模式校正後，名目 CPUE 序列與標準化 CPUE 序列的差異並不顯著。舉大目鮪區域 1N 的影響力分析結果為例，各漁船的模式估計係數變化頗大，也就是有些船的單位努力漁獲量明顯高出許多，而許多高效能船隻在某些年佔較高的比例，如 1979 年，則就導致那一年的名目 CPUE 的值就會較高，而經過納入漁船效應的模式標準化後，1979 年標準化 CPUE 的值就會明顯下降。

仍以大目鮪區域 1N 的影響力分析結果為例，每年作業努力量的空間分布可算是相當穩定，但在 2009 年開始在索馬利亞海域有活躍的海盜活動，所以之後三年，分布在索馬利亞海域的作業明顯下降，而 2012 年許多漁船返回這高大目

鮪漁獲率的區域作業，所以在 2012 年則有五度方格空間因子的年影響力就非常高。圖 45 與圖 48 顯示台灣漁船在大目鮪區域 1S 與區域 4 的捕獲大目鮪的漁獲能力有助年上升的趨勢，但在其他區域則無明顯變化趨勢。圖 51 顯示台灣漁船在黃鰭鮪區域 4 的捕獲黃鰭鮪的漁獲能力有助年上升的趨勢，但在其他區域則無明顯變化趨勢。

圖 53 至圖 54 顯示各區域大目鮪與黃鰭鮪標準化 CPUE 序列趨勢國際合作分析結果與本研究之比較圖，整體長期變化趨勢頗為一致。根據各魚種各區域本研究以及四國整合 CPUE 序列趨勢比較，整體看來，沒有值得需特別注意的現象。

大目鮪區域 1N 以及區域 1S 這個西熱帶區域的資源量指標趨勢顯示，1979 年至今，並沒有明顯變化趨勢，然自 2012 年之後，最近五年呈現逐年下降的短期趨勢。而在溫帶區域，1979 年至今，CPUE 序列也並沒有明顯變化趨勢，然最近兩年呈現相對較低的值。

黃鰭鮪在西熱帶區域的資源量指標趨勢顯示，1979 年 CPUE 逐年增加至 1987 年後，上下震盪至 2006 年，2006 年之後則一直下滑至 2010 年，2012 年上升至相對高點，但之後至今下降至長期來看相對低點，黃鰭鮪在東熱帶區域的資源量指標趨勢顯示，1989 年 CPUE 逐年緩慢下降至 2006 年，但呈現劇烈下降至 2016 上的長期來看相對低點，呼應目前黃鰭鮪資源評估為過漁的紅色警戒狀態。黃鰭鮪在西部溫帶區域的資源量指標趨勢顯示，1979 年 CPUE 逐年下降至 2011 年後，至今上下震盪。黃鰭鮪在東部溫帶區域的資源量指標趨勢顯示，1995 年 CPUE。

圖 57 至圖 65 顯示標準化模式套適殘差分析統計圖，有幾個模式殘差分布等相關檢視與常態分佈的假設頗有差距，有待繼續研判解讀。

第四章　檢討與建議

關於我國遠洋鮪延繩釣漁船漁撈能力分析，雖然根據之前的研究整體來看(fishing power)，這三十年台灣延繩釣漁業其漁撈能力未如預期成線逐步增加的趨勢。然而從本次分魚種分區域運用 CPUE 標準化模式各因子的解釋力以及影響性分析，確實了解到部分區域部分魚種確實高低效能的漁船比例年度間的差異會影響 CPUE 標準化的結果，因此建議 CPUE 標準化模式的主要因子應該要納入個別漁船效應，才能有更適切地的校正評估結果。

檢視殘差分析(模式檢測分析)顯示部分套適結果仍不盡理想，建議可以試試不同的資料轉換的方程式，現階段採用的是取對數，或許可以依殘差分布的特徵決定要用哪一種資料軟換，如開根號等。再檢視不同的資料轉換方式下，殘差分析的分布是否有改善。另一個方向是參考 IATTC 將體長資訊用於 CPUE 標準化分析，以及考慮時間與空間交互作用，考慮統計漁區分區，目標是要與資源評估的分區定義一致，然分區需考慮許多狀況不同角度考慮，如漁業選擇、標識放流顯示的資料。努力量不均勻分布的權重議題等。

關於 2002 年至 2004 年漁獲資料的 misreporting，未來或許可以嘗試從 VMS 資料著手，以可信度較高的 VMS 資料作努力量及其分部的掌握，再進行交叉比對，對於 misreporting 的概況作更進一步的了解，尋求解決之道。

另目前黃鰭鮪資源評估更新結果顯示印度洋黃鰭鮪資源仍呈現過漁狀態(overfished)與仍面臨過度捕撈的壓力(overfishing)。2018 年已有管理措施即將適用施行，我國印度洋鮪延繩釣漁業的漁獲量必須管控在 2014 年漁獲水準的 90%。而國內如何因應進行漁船配額管理勢在必行，以確保我國責任制漁業之形象與資源之永續。

第五章　成果效益說明及重大突破

5.1　學術成就、技術創新、經濟效益、社會影響

連續三年我國與日本、韓國科學家以及 IOTC 外聘獨立科學家共同探究台灣與日本之印度洋熱帶鮪類標準化 CPUE 變動趨勢的異同性及其可能之原由，有助於印度洋熱帶鮪類資源利用狀態有更清楚的認識。今年塞席爾亦加入共同合作計畫，中國大陸亦以觀察員的角色參與。透過公開透明的國際合作，逐步提升對於漁獲統計資料的深度理解與運用，以期資源評估結果更具確定性。

未來國際合作的研究成果不僅會運用在資源評估，日後亦會用在管理策略評估(MSE)，對於後續的漁業管理影響甚鉅。

參考文獻

Bentley, N., T. H. Kendrick, P. J. Starr and P. A. Breen (2012) Influence plots and metrics: tools for better understanding fisheries catch-per-unit-effort standardizations. ICES J. Mar. Sci., 69: 84-88.

Bigelow, K. A. and S. D. Hoyle (2012). Standardized CPUE for South Pacific albacore.

Hartigan, J. A. and M. A. Wong (1979). "Algorithm AS 136: A k-means clustering algorithm." Journal of the Royal Statistical Society.Series C (Applied Statistics) 28(1): 100-108.

Kaufman, L. and P. J. Rousseeuw (2009). Finding groups in data: an introduction to cluster analysis, John Wiley & Sons.

Maechler, M., P. Rousseeuw, A. Struyf, M. Hubert, K. Hornik, M. Studer and P. Roudier (2014). Package 'cluster'.

R Core Team (2014). R: A Language and environment for statistical computing. Vienna, Austria, R Foundation for Statistical Computing.

Yeh, Y.-M (2014). Analysis of Taiwanese longline fisheries based on operational catch and effort data for bigeye and yellowfin tuna in the Indian Ocean, IOTC WPTT16, Bali, Indonesia.

Winker, H., S. E. Kerwath and C. G. Attwood (2014). "Proof of concept for a novel procedure to standardize multispecies catch and effort data." Fisheries Research 155: 149-159.

備註：限於篇幅，省略附件之圖表。

附件 2

印度洋熱帶鮪類資源研究(107 年度)

行政院農業委員會 107 年度科技計畫期末研究報告
計畫名稱：印度洋熱帶鮪類資源研究
CPUE index and stock assessment of Taiwanese tropical tunas in the Indian Ocean
計畫主持人：南華大學葉裕民 副教授
計畫編號：107 農科-9.1.2-漁-F2(2)
全程計畫期間：107 年 1 月 1 日至 107 年 12 月 31 日

中文摘要

今年四度進行延續性進階國際合作，在台日韓與塞席爾四國作業日誌資料的保密性已充分考慮下，由 IOTC 外聘僱問整合四國作業層級的漁獲作業資料，估算出最具代表性的鮪延繩釣漁業印度洋大目鮪與黃鰭鮪的單位努力漁獲量標準化序列，提供與 2018 年印度洋鮪類委員會(IOTC)熱帶鮪類工作小組進行印度洋黃鰭鮪魚種資源評估。

本研究根據我國之漁獲資料採用國際合作發展出的研究分析架構以及 R 程式碼進行 CPUE 標準化序列，以利後續之分析比較。根據往年的先期研究對於我國漁業與漁業資料之概況與特性深度剖析，更新定義大目鮪與黃鰭鮪於資源評估用的統計漁區，並利用群集分析法區別出各漁業在各統計區的作業策略，並將此結果作為標的魚種的替代資訊，後續進行大目鮪與黃鰭鮪的 CPUE 標準化時，用群集組別效應納入模式以估算更適當的 CPUE 標準化序列。

本研究亦將觀察員資料與小釣漁業漁獲資料一併進行檢視分析，分析結果顯示我國延繩釣小釣漁業自 2010 後主要作業漁區已與大釣作業漁區高度重疊，但不同的是在東印度洋，如孟加拉灣仍有小釣在此海域捉黃鰭鮪。以小釣作業月別分布趨勢來看，除了 12 月份在偏重東印度洋作業外，其餘月份作業分布較無明顯模式，頗為分散。另分析 2017 年觀察員航次資料，以探討目前統計航次定義(船月)的妥適性，結果顯示原則上以船月為統計航次頗為合理，但是還是有些案例顯示魚種組成周與周之間亦會呈現明顯差異，日後可以嘗試比較以船周為統計航次定義的分析結果是否有顯著差異。

2018 年國際漁業組織 IOTC 更新黃鰭鮪漁獲資料與執行完整資源評估，認為此資源仍面臨過渡捕撈(overfishing)，且達過漁狀態(overfished)。最大持續生產量估計值約 35 萬公噸，而近五年平均每年印度洋黃鰭鮪總漁獲量約 42 萬公噸，而 2017 年約 44 萬公噸。目前黃鰭鮪的國際管理規範似乎並無法有效落實控制漁獲量，後續管理需要再檢討因應。2018 年印度洋大目鮪未做全面性完整評估，根據 2016 年資源評估結果認為此資源尚未面臨過渡捕撈(overfishing)，且未達過漁狀態(overfished)。各種資源評估模式分析結果皆顯示大目鮪目前資源量並未過漁，且亦未處於過漁狀態，然而目前大目鮪最大持續生產量(MSY)點估計為 10 萬四千噸，但是綜合各種資源模式評估結果可能範圍區間分布頗大，約介於 87,000~121,000 噸之間。近五年平均年漁獲量約為十萬公噸，2017 年大目鮪總漁獲量約為九萬公噸，皆未超過 MSY 水準。

Abstract

Bigeye and Yellowfin tuna CPUE standardization were analyzed. Updated Taiwanese longline fishery data to 2017 was used in this analysis. Cluster analysis was used to classify longline sets in relation to species composition of the catches to obtain target species proxy which can be used in CPUE standardization. All analyses were based on the approaches used by the collaborative workshop of longline data and CPUE standardization for bigeye and yellowfin tuna held in June 2018 in Keelung. Comparing to Joint CPUE indices for yellowfin tuna, Taiwanese CPUE indices showed a decreasing trend with smaller scale in tropical region. In 2017, yellowfin catch decreased to around 4,600 tons by Taiwanese longline fishery. Taiwan Tuna Association commented that the reduction of yellowfin catch in 2017 was due to quota management.

A new stock assessment was carried out for yellowfin tuna in 2018. On the weight-of-evidence available in 2017, the yellowfin tuna stock is determined to be overfished and subject to overfishing. The stock status determination changed in 2015 as a direct result of the large and unsustainable catches of yellowfin tuna taken over the previous three (3) years since 2012, and the relatively low recruitment levels estimated by the stock assessment model in recent years. Resolution 18/01 did not work out to reduce the catches.

No new stock assessment was carried out for bigeye tuna in 2018, thus, the stock status is determined on the basis of the 2016 assessment and other indicators presented in 2018. On the weight-of-evidence available in 2018, the bigeye tuna stock is determined to be not overfished and is not subject to overfishing.

第一章　前言

自 1985 年後，印度洋大目鮪與黃鰭鮪一直都是台灣遠洋鮪延繩釣船隊在印度洋主要利用之漁業資源。而印度洋大目鮪與黃鰭鮪資源狀態一直也是國際漁業組織 IOTC 關注的事項。以漁業利用強度與漁獲統計資料品質的角度而言，印度洋熱帶鮪類的資源評估工作非常倚賴臺灣與日本的 CPUE 標準化序列指標。然而若視臺灣與日本的 CPUE 標準化序列皆為資源變動的指標，如何解釋彼此指標的變動關係及與資源量的相互關係一直是被探討的議題。在印度洋，台灣和日本鮪延繩釣船隊的作業型態，長年來包括標的魚種的移轉，作業空間的分布各有其歷史變革。以近幾年來看，台灣一直以大目鮪為標的魚種，而日本則以黃鰭鮪為標的魚種。且台灣的作業分布遍及印度洋大部分海域，而日本作業分布較為侷限，百分之七十的黃鰭鮪漁獲量是來自於莫三比克海峽附近海域，所以若大目鮪與黃鰭鮪資源評估只用日本的資料，會有代表性的問題。然而 1980 年後，依據台灣漁獲日誌資料所獲得之印度洋黃鰭鮪與大目鮪的 CPUE 標準化序列趨勢與日本的序列趨勢並不一致。因此三年前透過 IOTC、IOTC 外聘科學顧問以及台日以及韓塞席爾四國國際合作研究，整合四國作業層級資料，估算整合性 CPUE 標準化序列以作為最佳資源變動的指標。根據現階段合作結果認為，差異性主要源自於原始資料(名目漁獲努力量，Nominal CPUE)的本質，而非資料處理或研究方法的變異。我國船隊作業日誌回收率年間變化頗大，從 1979 年約 63%，到 1992 年，回收率最低，只有 4%。

整體而言，1984 年到 2002 年回收率在五成以下，因過低的回收率可能會降低作業日誌反映整個船隊作業概況的代表性。且檢視台日韓三國在印度洋赤道海域年別每次作業大目鮪漁獲尾數的頻度分佈圖，在 1977~2001 年以及 2005~2008 年年間，三國的分佈頗為相似。但在 1983~1991 年低漁獲(如每次作業捕獲 20 尾大目鮪)各國的變動幅度較大且不甚一致外，其中 2002~2004 年台灣的分佈模式異常，且和他國相比，平均而言，每次作業大目鮪漁獲尾數高出許多。然而這三年台灣作業分佈似乎無明顯變化，推測此和 2002-2004 年我國大西洋與印度洋之間發生的洗魚事件有關，因此估算整合性 CPUE 標準化序列時，只取我國 2005 年(含)之後的作業日誌資料。目前大目鮪與黃鰭鮪資源評估雖採用的延繩釣漁業整合性 CPUE 標準化序列，然未來各國仍須分別提供各國之 CPUE 標準化序列以綜合分析比較，因此台灣與日本序列趨勢不一致的議題仍須繼續探究。

為理解台灣與日本序列趨勢不一致的可能原因，已嘗試由歷年兩國標的魚種的移轉與作業漁區的重疊性等面向探討。關於兩國延繩釣漁業的漁業選擇係數(Selectivity)是否有差異尚未同步探討深究。因此探討的重點會針對我國漁業利用聚集分析，根據每次航次漁獲組成的相似性進行分類所鑑別出之各種作業策略做更深入的分析。除了依各作業策略檢視分析所捕獲之大目鮪與黃鰭鮪體長分布特性外，亦將再依時空特徵進行分析。因目前以魚種組成為依據所進行的聚集分析所得的判斷上，要將以大目鮪或以黃鰭鮪為標的魚種的作業紀錄區分仍有其難度，所以若將大目鮪與黃鰭鮪漁獲體長的資訊納入聚集分析的依據，尋求較有效的作業策略的鑑別性。另為估求更妥適的標準化 CPUE 序列，尚有許多仍待處理的議題。

本研究擬針對下列幾項問題進行探討：1. 航次的定義，先前的研究在資料分析上是以同一艘船同一個月份的作業視為同一航次，然原始漁獲日誌作業紀錄

記有航次資訊，雖部分作業航次資料登錄不完整，但應仍可作為檢視目前資料分析所用的航次定義是否合宜，或是否有其它更適切的航次定義；2. 先前研究之GLM 模式套適殘差分析顯示殘差分佈與殘差常態分佈的假設未完全符合，建議再進行 GLM 分析前，可從其他的資料轉換(Data transformation)方式進行探討，嚐試運用開根號或其他函數轉換取代原有的對數轉換，再檢視 GLM 模式套適後的殘差分析是否呈現系統性偏差。

針對依據台灣商業性漁獲統計資料估得之印度洋黃鰭鮪與大目鮪的單位努力漁獲量(Catch per unit effort, CPUE)標準化序列趨勢與日本的序列趨勢不一致的議題，已於 2015 年開始進行了三年的國際合作研究。這三年進行了台、日、韓與塞席爾各國漁業與漁業資料之概況與特性深度剖析，並考慮空間、標的魚種與船隊漁獲能力等因子，分別估算各國印度洋大目鮪與黃鰭鮪魚種標準化 CPUE 序列趨勢，以及整合各國資料後再估算標準化 CPUE 序列。主要研究成果包括 1. 篩選有效之作業層級資料的條件設立會顯著影響後續 CPUE 標準化估算結果，建議篩選條件的設定必須審慎探究資料來源以及代表意義；2. CPUE 標準化模式因子的選用，五度方格漁區、標的魚種的選用指標與船隊之漁撈能力等因子顯著影響 CPUE 變動趨勢的估算，建議後續應納入此些因子進行 CPUE 標準化的分析；3. 因我國印度洋鮪延繩船隊漁業活動之漁獲作業日誌資料回收率於 2000 年前年間變化較大且部份年度回收率偏低，且 2002-2004 年我國大西洋與印度洋之間發生的洗魚事件，檢視這三年漁獲作業日誌，整體船隊普遍漁獲表現異常，且根據現有資料無法進行有效辨別個別船隻填報可信賴度，為確保整合 CPUE 標準化序列的適當性，因此只採用我國 2005 年後之漁獲作業日誌資料納入整合分析；4. 關於遠洋鮪延繩釣漁業或船隊之漁撈能力 (fishing power) 一直是目前認為標準化 CPUE 序列趨勢若要用來作為資源量變動指標是必要可慮的議題。我國印度洋鮪延繩釣漁船大目鮪漁撈能力在核心區域從 1979 年的 0.9 些微增加至 2012 年的 1.1。 特別的是在南印度洋海域在 1979 年至 2012 年年間從 0.7 明顯增至 1.4。我國印度洋鮪延繩釣漁船黃鰭鮪漁撈能力在核心區域從 1979 年的 0.7 些微增加至 1993 年的 1.0，之後幾乎皆維持在穩定的水準。 而在南印度洋海域在 1979 年以及 1989 年有較高的漁撈能力 1.2，在 1992 年以及 1993 年有較低的漁撈能力 0.6 外，其他年度至 1996 年都約為 1.0，自 1996 年後則持續增加至 2012 年的 1.3 年。整體而言，我國印度洋鮪延繩釣漁船大目鮪與黃鰭鮪漁撈能力並不如預期得和日本一樣呈現明顯上升趨勢，因此目前我國漁撈能力變異的機制尚無法掌握；5. 群集分析法區別出我國印度洋鮪延繩釣漁業在各統計區的作業策略，也就是各組別有其特有的漁獲組成、作業位置、作業季節、每筐鉤數等的分布特性。如在西南印度洋統計漁區檢視出我國有明顯的油甘漁業於此，故後續進行大目鮪與黃鰭鮪的 CPUE 標準化時可以用群集組別效應或剔除油甘漁業資料估算更適當的 CPUE 標準化序列。計畫目標是檢視與分析我國印度洋熱帶鮪類作業層級資料與觀察員資料之漁獲與體長資料，以掌握漁業利用資源動態發展。同時協助檢視資料品質將有疑義之資料回報漁業署及資料庫管理單位，並提出觀察員資料之改善建議。於 4 月底前針對前一年度印度洋鮪類委員會(IOTC)熱帶鮪類工作小組會議評估印度洋大目鮪與黃鰭鮪資源狀況之結果提出中文摘要。配合印度洋鮪類委員會(IOTC)執行印度洋大目鮪與黃鰭鮪魚種資源評估，進行印度洋大目鮪與黃鰭鮪 CPUE 標準化研究分析，並提出相關研究報告，以因應 2018 年國際漁業組織印度洋鮪類委員會(IOTC)熱帶鮪類資源指標更新評估。

第二章　實施方法

2.1 台灣作業層級資料與漁業概況分析

本研究提請漁業署提供一度空間解析度航次原始作業日誌、觀察員資料、歷史 VMS 資料、漁獲統計書、核銷資料以及進出港資料。針對我國遠洋鮪延繩釣漁獲統計資料庫之漁獲努力量與各魚種漁獲量時間與空間分佈等項目資料進行深度檢視，以掌握漁業歷年發展動態。

2.2 聚集分析(Cluster Analysis)

因分析台灣印度洋鮪延繩釣漁業標的魚種黃鰭鮪與大目鮪的漁獲率時，若只考慮作業漁季、作業漁區以及漁獲組成等因子，而不考慮作業之標的魚種的移轉，並無法對於印度洋黃鰭鮪及大目鮪漁獲率的變異進行適當的掌握。 因此本研究利用聚集分析，根據每次作業或航次（船月別）漁獲組成的相似性進行分類，期能鑑別每次作業或航次的標的魚種，進而將組別視作為一目標魚種(或作業策略)的替代指標。 考慮以航次別作為一分析單位是因縱使標的魚種不變，時空變異之下，其漁獲組成的比例仍存有異質性。 因此預計以航次資料為一分析單位，進而設計分析架構，滿足組別內的變異程度小於組別間的變異，使聚集分析結果更具確適性。

因此考慮每次作業的魚種漁獲，包括黃鰭鮪、大目鮪、長鰭鮪、黑鮪、南方黑鮪、劍旗魚、旗魚類(黑皮旗魚、白皮旗魚、紅肉旗魚)、鯊魚以及其他魚類的漁獲組成。

此研究採用的方法主要參考 Bigelow and Hoyle(2012)以及 Winker *et al.* (2014)的研究方法。首先去除無任何漁獲的作業紀錄，計算每筆作業紀錄各魚種漁獲尾數佔總漁獲尾數的百分比。 採用兩種資料處理方式進行聚集分析，第一種方式是將漁獲組成資料進行轉換以避免某些平均漁獲量較大的魚種會影響分析的有效性。轉換方式即是標準化常態分佈的過程。 而另一種方式即是不作任何資料轉換。

根據去年採用三種聚集分析方法的經驗，此次選用為 Ward hclust。 階層式聚集分析(hierarchical cluster analysis, Ward method)乃先利用統計分析軟體 R 的 dist 函數功能計算資料結構異質性的距離，然後再用 hclust 函數功能，給定參數 Ward.D 進行分析。

一般而言，聚集組別的選定頗為主觀。 本研究根據漁業實況，判定至少會有兩種不同作業策略存在於船隊中，一是以大目鮪為標的魚種，二是以長鰭鮪為標的魚種。 組別選定會參考不同的統計分析結果。

2.3 漁獲能力分析與泛線性模式（Generalized Linear Model, GLM）

分別針對大目鮪與黃鰭鮪區依同質性原則，將印度洋劃分成數個統計漁區，分魚種分區分別進行單位努力漁獲量標準化研究，利用泛線性模式估計台灣鮪延繩釣漁業利用印度洋大目鮪與黃鰭鮪單位努力漁獲量標準化變動趨勢部分採用的基本模式是以時間(年季)、五度方格空間、漁船以及作業策略(標的魚種)組別為主要因子。並進一步分析模式殘差分佈，再針對各可能的時空交互因子、多種殘差機率分佈假設或嘗試與泛線性模式的各類變異擴充模式進行模式修正嘗試，

以達最佳模式套適效果，估計最適資源量變動指標。並配合提供印度洋鮪類委員會(IOTC)執行大目鮪與黃鰭鮪資源評估，提出相關研究報告。

第三章　結果與討論

3.1　印度洋大目鮪與黃鰭鮪相關文獻回顧

2018 年黃鰭鮪的總配額管理措施似乎不成功，相關國際管理組織報告探討其他可能的管理方案，如控制投入的努力量，尤其是針對圍網。但是相對的監控機制若要即時費力費錢，有著各種落實困難。目前三大洋大西洋的大目鮪用總配額管理亦不成功。

圍網漁業捕獲相當比例的熱帶鮪類幼魚，所以許多研究針對圍網的集魚器進行研究，包括從嘗試給予圍網漁業用可生物分解的集魚器此名詞一個明確的定義，鑒於各漁業組織鼓勵圍網漁業用可生物分解的集魚器，所以這相關研究對於可生物分解的集魚器應該用的材質進行探討。另對於 FAD 規範漁業管理措施的探討，今年西班牙漁業研究所 AZTI 提出關於集魚器相關資料蒐集與提報最佳標準系統與流程的建議報告，目標是希望整合各大洋的資料。

韓國關於集魚器的相關研究，兩種集魚器作實驗，量測集魚器移動的速度與狀況(水流擾動強度的互動)，相對於魚(這裡實驗的魚種是鯖魚) 的速度與狀況，但是如何將此實驗的結果最後運用在鮪魚(不僅魚體形狀和移動能力等存在差異)上，或許還有研究的必要，整體研究的目的是希望能減少與混獲物種(鯊、龜等)纏繞。

3.2　印度洋大目鮪與黃鰭鮪資源狀況與各國漁業利用概況

關於大目鮪物種漁業概況，近四年(2013~2016)，主要的利用漁業為超低溫和生鮮延繩釣漁業與圍網。超低溫和生鮮延繩釣漁業漁獲量佔總漁獲量的一半，圍網漁獲量佔三成。另近幾年斯里蘭卡和伊朗的刺網漁業持續發展，漁獲量呈增加的趨勢。主要船隊依次為印尼(延繩釣與圍網)、台灣(延繩釣)、塞席爾(延繩釣與圍網)和歐盟西班牙(圍網)。印度洋大目鮪年總漁獲量從 1970 年代的兩萬公噸開始，因 1980 年歐盟圍網加入，於 1990 年增加至約 15 萬公噸，後因海盜活動等原因漁獲量下降至最近幾年約為 10 萬公噸。

關於黃鰭鮪物種漁業概況，1980 年後，家計型漁業逐漸發展，近四年(2013~2016)，商業型漁業和家計型漁業漁獲量各佔一半，各約為 20 萬公噸。主要船隊依次為歐盟西班牙(圍網)、馬爾地夫(手釣與一桿釣)、伊朗(刺網)與印尼(延繩釣與手釣)。印度洋黃鰭鮪年總漁獲量於 1950 至 1980 年早期維持在約七萬公噸的水準，到 1993 年，因為圍網與延繩釣漁業的加入，漁獲量增加至約 40 萬公噸，2003 年和 2006 年年漁獲量高達 50 多萬公噸。2007 至 2009 年因海盜活動，許多船隊作業漁場東移或南移，漁獲量下降至 2004 年漁獲水準的六成，但 2012 年後又恢復至約 40 萬公噸。近五年平均每年印度洋黃鰭鮪總漁獲量約 42 萬公噸，而 201 年約 44 萬公噸。

依據印度洋鮪類管理委員會 2017 年第 19 屆熱帶鮪類工作小組之會議報告(cite)以及印度洋鮪類管理委員會 2017 年第 20 屆科學委員會之會議報告，目前國際漁業組織管理情形，大目鮪的資源狀態評估進展是 2017 年未做全面性完整評估。根據 2016 年印度洋大目鮪的資源評估結果認為此資源尚未面臨過渡捕撈(overfishing)，且未達過漁狀態(overfished)。各種資源評估模式分析結果皆顯示大目鮪目前資源量並未過漁，且亦未處於過漁狀態，然而目前大目鮪最大持續生產量(MSY)點估計為 10 萬四千噸，但是綜合各種資源模式評估結果可能範圍區間

分布頗大，約介於 87,000~121,000 噸之間。2015 年親魚量估計約為初始親魚量的 38%，且為可供給最大持續生產量的親魚量之 129%。相對於 2013 年的資源評估結果，生物量略微下降(from 144 to 129% SB/SBMSY)以及漁業壓力略為增加(from 42 to 76% F/FMSY)。近五年平均年漁獲量約為十萬公噸，2016 年大目鮪總漁獲量約為九萬公噸，皆未超過 MSY 水準。輔以 2017 年的各種資源量指標資訊，判定大目鮪資源目前仍處於未過漁，且亦未處於過漁狀態。

黃鰭鮪的資源狀態評估進展是因 2015 年黃鰭鮪評估結果為已面臨過渡捕撈(overfishing)，且達過漁狀態(overfished)。今年 2018 年再次進行黃鰭鮪資源評估，資源狀況仍處於紅字警戒，此資源仍面臨過渡捕撈(overfishing)，且達過漁狀態(overfished)。最大持續生產量估計值約 35 萬公噸。2017 年親魚量估計約為初始親魚量的 28%，且為可供給最大持續生產量的親魚量之 80%。資源評估結果顯示，親魚量仍過低(SB/SBMSY=0.80)以及漁業壓力仍過高(F/FMSY=1.39)。

大目鮪物種管理狀態簡述如下:自 2007 年後延繩釣努力量顯著減少，漁獲壓力減低。2016 年進行風險評估，估計若維持在目前的漁獲量水準(九萬公噸以內)，以最大持續生產量為基準的參考點為判斷依準，2018 年和 2025 年資源狀態應該可以維持穩健狀態。資源可能避免面臨過漁狀態。若在努力量持續下降，且漁獲量持續低於 MSY 水準下，則就不需要有立即性的管理措施，但仍需加強對於資料收集及分析，以降低評估的不確定性。

黃鰭鮪物種管理狀態簡述如下:鑒於資源狀態不佳，近幾年漁獲量又居高不下，估計這幾年的補充量又低，所以目前進行復育計畫 Resolution 18/01，限制漁獲量維持在 2014/2015 年的漁獲水準的 90%以下(延繩釣漁業)。然而各漁業國黃鰭鮪管理 18/02 遵守情形是，商業船隊都還算遵守，但是許多沿岸國的黃鰭鮪漁獲量都超過允許的配額量，整理而言，總漁獲量並未如期控管，甚至較去年都還高(高出 3%)，現行的管理措施未奏效。

圖九至圖十三為我國延繩釣漁業歷年在印度洋作業努力量、每筐鉤數、大目鮪與黃鰭鮪漁獲量與單位努力漁獲量的空間分布圖。近十年我國作業區域已逐漸縮減，現階段主要分布在西熱帶印度洋抓大目鮪，以及溫帶海域抓長鰭鮪與油魚。2011 後每筐鉤數整體而言都增加，可能是許多漁船漁具裝備置換為美式滾筒，依次作業可以加多鉤數。此變革應進一步了解探討，因其會影響後續資料解讀運用。

圖十四至圖二十一是我國延繩釣小釣漁業歷年在印度洋作業努力量、大目鮪與黃鰭鮪漁獲量的空間分布圖。可以看到 2010 後主要作業漁區已與大釣作業漁區高度重疊，但不同的是在東印度洋，如孟加拉灣仍有小釣在此海域捉黃鰭鮪。月別分布趨勢來看，除了 12 月份在偏重東印度洋作業外，其餘月份作業分布較無明顯模式，頗為分散。

3.3 聚集分析結果

圖二十二至圖二十三是本研究採用之大目鮪與黃鰭鮪的漁區定義。表 3 與表 4 顯示分別依據大目鮪與黃鰭鮪漁區定義，各區域聚集分析方法的結果。以黃鰭鮪(RegY2)漁區定義第 2N 區域為例，方法 hcltrip 結果清楚顯示聚集一，主要目標魚種為大目鮪；聚集二，主要目標魚種包括大目鮪，次之為黃鰭鮪以及劍旗魚也佔一定的比例；聚集三，主要目標魚種包括大目鮪、劍旗魚與黃鰭鮪；聚集四，主要目標魚種大目鮪與其他魚種，其次為黃鰭鮪；聚集五，主要目標魚種包括黃鰭鮪、次之為大目鮪。24 至圖 45 呈現各區域內各聚集作業特性、作業空間分佈以及漁獲組成特性，各聚集的作業空間分佈相對於其他特徵呈現比較明顯的區隔。

以黃鰭鮪(RegY2)漁區定義第 2N 區域為例(圖 38)，各類統計分析結果顯示將作業資料分成五個聚集群組為最佳。而圖 42 顯示以黃鰭鮪(RegY2)漁區定義第三區域為例，各聚集群組內的作業特徵。如第四類聚集群組應對應的是自 2005 年後以油魚為標的魚種的作業紀錄，而第一類聚集群組則對應的是以長鰭鮪為標的魚種的作業紀錄，而第二類聚集群組則對應的是以大目鮪與黃鰭鮪為標的魚種的作業紀錄。我國作業日誌已經從 2009 後有獨立紀錄油魚漁獲，本研究根據此資訊可確認聚集分析在缺乏獨立油魚漁獲紀錄的往年，仍可以根據漁獲組成以聚集分析成功隔離出油魚漁業，並將此類作業努力量剔除於熱帶鮪類 CPUE 標準化的分析研究。

圖 58 至圖 60 是探討聚集選擇標準，也就是若某聚集的作業捕獲甚少比例的標的魚種，則代表此類作業紀錄並無包含標的魚種的漁獲資訊，將不納入 CPUE 標準化模式分析。而低於多少比例才適當，則可以就資料樣本數與估計之序列的穩定度來判斷。結果顯示相較於低於平均比例的篩選原則，小於 5% (也就是相當低的比例)的篩選原則較合適，因為保留較多的樣本而估計之序列的穩定度也較高。

另分析 2017 年觀察員航次資料(圖 61 至圖 63)，將每一航次作業位置繪製於地圖上，並觀察相對應的漁獲組成，以周別為時間單位檢視目前統計航次定義(船月)是否妥適。結果顯示原則上以船月為統計航次頗為合理，但是還是有些案例或許魚種組成周與周之間亦會呈現明顯差異，或許日後可以試著比較若以船周為統計航次的分析結果是否有顯著差異。

3.4 CPUE 結果

根據 Constant Lognormal GLM 的分析結果，表 5 至表 13 與圖 48 至圖 57 呈現各區域大目鮪與黃鰭鮪 CPUE 標準化模式，各因子對於 CPUE 序列趨勢的解釋力與影響力之統計分析表。簡單來說，由影響力分析可以了解名目 CPUE 序列與標準化 CPUE 序列的差異主要是來自於哪一個主要因子的影響。 隨然某個因子可以解釋很大的 CPUE 值的變異，但是加入此因子並不一定會有明顯的校正效果。原因是可能每年這個因子的實際變數值分布會很類似，舉例來說，季節或許可以解釋很大程度 CPUE 的變異，然每年作業努力量在各季節的作業分布可能很類似，因此模式校正後，名目 CPUE 序列與標準化 CPUE 序列的差異並不顯著。舉大目鮪區域 1N 的影響力分析結果為例，各漁船的模式估計係數變化頗大，也就是有些船的單位努力漁獲量明顯高出許多，而許多高效能船隻在某些年佔較高的比例，如 1979 年，則就導致那一年的名目 CPUE 的值就會較高，而經過納入漁船效應的模式標準化後，1979 年標準化 CPUE 的值就會明顯下降。

仍以大目鮪區域 1N 的影響力分析結果為例，每年作業努力量的空間分布可算是相當穩定，但在 2009 年開始在索馬利亞海域有活躍的海盜活動，所以之後三年，分布在索馬利亞海域的作業明顯下降，而 2012 年許多漁船返回這高大目鮪漁獲率的區域作業，所以在 2012 年則有五度方格空間因子的年影響力就非常高。圖 49 與圖 52 顯示台灣漁船在大目鮪區域 1S 與區域 4 的捕獲大目鮪的漁獲能力有助年上升的趨勢，但在其他區域則無明顯變化趨勢。圖 56 顯示台灣漁船在黃鰭鮪區域 4 的捕獲黃鰭鮪的漁獲能力有助年上升的趨勢，但在其他區域則無明顯變化趨勢。

圖 64 至圖 65 顯示各區域大目鮪與黃鰭鮪標準化 CPUE 序列趨勢國際合作分析結果與本研究之比較圖，整體長期變化趨勢頗為一致。根據各魚種各區域本

研究以及四國整合 CPUE 序列趨勢比較，在熱帶海域，我國黃鰭鮪的 CPUE 序列趨勢較國際合作分析結果而言，下降的幅度稍微有所緩和。

大目鮪區域 1N 以及區域 1S 這個西熱帶區域的資源量指標趨勢顯示，1979 年至今，並沒有明顯變化趨勢，然自 2012 年之後，最近五年呈現逐年下降的短期趨勢。而在溫帶區域，1979 年至今，CPUE 序列也並沒有明顯變化趨勢，然最近兩年呈現相對較低的值。

黃鰭鮪在西熱帶區域的資源量指標趨勢顯示，1979 年 CPUE 逐年增加至 1987 年後，上下震盪至 2006 年，2006 年之後則一直下滑至 2010 年，2012 年上升至相對高點，但之後至今下降至長期來看相對低點，黃鰭鮪在東熱帶區域的資源量指標趨勢顯示，1989 年 CPUE 逐年緩慢下降至 2006 年，但呈現劇烈下降至 2016 上的長期來看相對低點，呼應目前黃鰭鮪資源評估為過漁的紅色警戒狀態。黃鰭鮪在西部溫帶區域的資源量指標趨勢顯示，1979 年 CPUE 逐年下降至 2011 年後，至今上下震盪。黃鰭鮪在東部溫帶區域的資源量指標趨勢顯示，今年給予較嚴格的樣本代表性標準，所以樣本數較少，有許多缺失值，不易比較。

圖 66 至圖 77 顯示標準化模式套適殘差分析統計圖，有幾個模式殘差分布等相關檢視與常態分佈的假設頗有差距，發現大目鮪較適合用 constant lognormal model，而黃鰭鮪較適合用 delta lognormal model。應該是大目鮪是我國延繩釣的主要標的魚種，而黃鰭鮪較屬於混獲魚種。

根據圖 78 的漁區定義，以我國觀察員資料進行聚集分析，以檢視各聚集大目鮪與黃鰭鮪漁獲體長是否有明顯差異。圖 79 至圖 82 並初步檢視各作業組別以及各區域各群集 (clusters)之觀察員紀錄體長資料分布特性。尚無觀察到聚集間明顯體長分布特性。

第四章　檢討與建議

國際合作進行整合 CPUE 標準化分析，主要是針對依據台灣商業性漁獲統計資料估得之印度洋黃鰭鮪與大目鮪的 CPUE 標準化序列趨勢與日本的序列趨勢不一致的議題，今年度六月在台進行第四次進階國際合作。此次國際合作參與者包括台日韓與塞席爾科學家以及 IOTC 科學家與外聘科學家。在台日韓塞席爾四國作業日誌資料的保密性已充分考慮下，進行各漁業與漁業資料之概況與特性深度剖析，並考慮空間、標的魚種與船隊漁獲能力等因子，並根據相同的研究分析架構分別估算各國印度洋大目鮪與黃鰭鮪魚種標準化 CPUE 序列趨勢。

今年的國際合作成果在 IOTC 熱帶鮪類工作小組會議上發表，有許多的意見，給予了未來研究的方向，整體而言，仍受國際漁業管理組織肯定，並鼓勵日後更進一步的國際合作。透過公開透明的國際合作，逐步提升對於漁獲統計資料的深度理解與運用，以期資源評估結果更具確定性。目前建議在明年的四月底左右大西洋黃鰭鮪資料準備會議在西班牙馬德里會後就地進行國際合作研究，但仍待議與確認。

未來一年會以此合作模式，將研究內容延展是體長資料，並列為建議研究項目最優先的順位。也就是 IOTC 秘書處明年計畫開啟國際合作研究(此一研究項目今年已被列為高度優先執行項目)，請外聘顧問(Simon Hoyle)與各國(預計包括台灣、日本與韓國)漁業管理單位以及處理體長資料的單位聯繫、討論合作的方式等細節。若檢視漁獲體長資料呈現於魚體偏小，或漁獲平均體長下降，或小魚比例偏高，或許需進一步分析是否資源呈現生長型過漁(growth overfishing)現象，因為有上述情況有可能是漁業多在魚體尚未達大最適體長前捕獲，需進一步模式分析確認。

台灣提交之 2001-2004 年台灣延繩釣漁業大目鮪年總漁獲量(Task I)以及大目鮪產證資料不一致，甚至大目鮪產證資料所紀錄的漁獲量高於大目鮪年總漁獲量。這項議題今年再度被指出，建議若我國應給予正式回應。

今年針對我國的熱帶鮪類的體長資料諸多質疑討論，最需要處理的是工作小組會因此進一步質疑我國作業日誌對於漁獲的低報(不報小魚)，質疑小魚被丟棄。因為許多會員從 ICCAT 的相關會議與報告(參見以下截圖)中得到一些陳述。雖然會議尚有做澄清，但是或許我國有多方說法，各國抱持狀況仍不明確的態度，建議我國應對於此議題，在三大洋區有統一的說法與立場。

第五章　成果效益說明及重大突破

5.1　學術成就、技術創新、經濟效益、社會影響

四年來我國與日本、韓國與塞席爾科學家以及 IOTC 外聘獨立科學家共同探究印度洋熱帶鮪類標準化 CPUE 變動趨勢的合理估算方法，合作過程與成果已於四屆的 IOTC 熱帶鮪類工作小組會議中發表數篇研究報告，有助於印度洋熱帶鮪類資源利用狀態有更清楚的認識。因仍有許多疑慮待釐清，每年的國際合作均受國際漁業管理組織期待。透過公開透明的國際合作，逐步提升對於漁獲統計資料的深度理解與運用，以期資源評估結果更具確定性。整體而言，除了透過深度的國際合作處理長久以來關於印度洋熱帶鮪類 CPUE 標準化序列趨勢不確定性的議題外，我國持續提供國際漁業組織我國漁業動態資訊對於我國的形象與漁業資源評估的可信度皆有所提升。

參考文獻

Bigelow, k. and Hoyle, S.D., 2012. Standardized CPUE for South Pacific Albacore, WCPFC-SC8, Busan, Republic of Korea.
Chang, S.-K., Hoyle, S. and Liu, H.-I., 2011. Catch rate standardization for yellowfin tuna (Thunnus albacares) in Taiwan's distant-water longline fishery in the Western and Central Pacific
Ocean, with consideration of target change. Fisheries Research, 107(1-3): 210-220.
He, X., Bigelow, K.A. and Boggs, C.H., 1997. Cluster analysis of longline sets and fishing strategies within the Hawaii-based fishery. Fisheries Research, 31(1-2): 147-158.
Hoyle, S.D., 2014. Spatial considerations in bigeye and yellowfin CPUE from Japanese and Taiwan,China longline fisheries in the Indian Ocean, IOTC WPTT16, Bali, Indonesia.
Hoyle, S.D., Langley, A.D. and Campbell, R.A., 2014. Recommended approaches for standardizing CPUE data from pelgic fisheries, WCPFCSC10, Majuro, Republic of the Marshall Islands.
Hoyle SD, Okamoto H, Yeh Y-M, Kim ZG, Lee SI &Sharma R, 2015. Report of the 2nd CPUE Workshop on Longline Fisheries, 30 April – 2 May 2015, IOTC WPTT17. Montpellier, France.Hoyle SD, Yeh Y-M, Chang S-T &Wu R-F, 2015. Descriptive analyses of the Taiwanese Indian Ocean longline fishery, focusing on tropical areas. IOTC WPTT17 Montpellier, France.Hoyle SD, Doo Nam Kim, Sung Il Lee, Takayuki Matsumoto, Kaisuke Satoh, and Yu-Min Yeh. 2016. Collaborative study of tropical tuna CPUE from multiple Indian Ocean longline fleets in
2016. IOTC-2016-WPTT18-14.
Hoyle SD, et al. 2017. Collaborative study of tropical tuna CPUE from multiple Indian Ocean longline fleets in 2017. IOTC-WPTT19-32, Victoria, Seychelles.
Hoyle SD, Satoh K and Matsumoto T. 2017. Exploring possible causes of historical discontinuities in Japanese longline CPUE. IOTC-WPTT19-33, Victoria, Seychelles.
Hoyle SD, Satoh K and Matsumoto T. 2017. Selectivity changes and spatial size patterns of bigeye and yellowfin tuna in the early years of the Japanese longline fishery. IOTC-WPTT19-34, Victoria,
Seychelles.
Hoyle SD, Satoh K and Matsumoto T. 2017. Exploration of Japanese size data and historical changes in data management. IOTC-WPTT19-35, Victoria, Seychelles.
Hoyle SD. 2017. Regional scaling factors for Indian Ocean stock assessments. IOTC-WPTT19-36, Victoria, Seychelles.IOTC, 2014. Report of the Seventeenth Session of the IOTC Scientific Committee, IOTC SC17, Seychelles.
Matsumoto T, et al. 2017. Consideration on high jump of Japanese longline CPUE for bigeye and yellowfin tuna in the late 1970s in the Indian Ocean. IOTC-2017-WPTT19-26.
Maunder, Mark N., John R. sibert, Alain Fonteneau, John Hampton, Pierre Kleiber, and Shelton J. Harley. 2006. Interpreting catch per unit effort data to assess the status of individual stocks and communities. ICES Journal of Marine Science, 63: 1373-1385.
Okamoto, H., 2014a. CPUE of bigeye and yellowfin tuna caught by Japanese longliner in the Indian Ocean standardized by GLM considering several aspects of area, catchability and data resolution, IOTC WPTT16, Bali.
Okamoto, H., 2014b. Provisional study on comparison of CPUE trend of bigeye and

yellowfin tuna between Japanese and Taiwan-China longline fisheries based on whole and shared strata in the Indian Ocean, IOTC WPTT16, Bali, Indonesia.
Okamoto, S.D.H.a.H., 2011. Analyses of Japanese longline operational catch and effort for bigeye and yellowfin tuna in the WCPO, WCPFCSC7-2011/SA IP-01,
Pohnpei, Federated States of Micronesia. Sofia Ortega-Garcia, Daniel Lluch-Belda and Pablo Arenas Fuentes. 2003. Spatial, seasonal, and annual fluctuations in relative abundance of yellowfin tuna in the eastern Pacific Ocean during 1984–1990 based on fishery CPUE analysis. Bulletin of marine science, 72(3):613-628.
Yeh, Y.-M., 2014. Analysis of Taiwanese longline fisheries based on operational catch and effort data for bigeye and yellowfin tuna in the Indian Ocean, IOTC WPTT16, Bali, Indonesia.
Yeh Y-M &Chang S-T, 2015. Updated CPUE standardizations for bigeyeand yellowfin tuna caught by Taiwanese longline fishery in the Indian Ocean using generalized linear model. IOTC-WPTT17,
Montpellier, France.
Yeh Y-M &Chang S-T, 2016. Updated CPUE standardizations for bigeye and yellowfin tuna caught by Taiwanese longline fishery in the Indian Ocean using generalized linear model. IOTC-WPTT18, Victoria, Seychelles.
Yeh Y-M, Hoyle S and Chang S-T. 2017. Updated CPUE standardizations for bigeye and yellowfin tuna caught by Taiwanese longline fishery in the Indian Ocean, using Generalized Liner Model. IOTC-WPTT19-31, Victoria, Seychelles.
Winker, H., S. E. Kerwath and C. G. Attwood (2014). "Proof of concept for a novel procedure to standardize multispecies catch and effort data." Fisheries Research 155: 149-159.

備註：限於篇幅，省略附件之圖表。

附件 3

印度洋熱帶鮪類資源研究(108 年度)

行政院農業委員會 108 年度科技計畫期末研究報告
計畫名稱：印度洋熱帶鮪類資源研究(III)
CPUE index and stock assessment of Taiwanese tropical tunas in the Indian Ocean
計畫主持人：南華大學葉裕民 副教授
計畫編號：108 農科-9.1.2-漁-F2(2)
全程計畫期間：108 年 1 月 1 日至 108 年 12 月 31 日

中文摘要

本計畫主要目標為檢視與分析我國印度洋熱帶鮪類作業層級資料與觀察員資料之漁獲與體 長資料，以掌握漁業利用資源動態發展。配合印度洋鮪類委員會(IOTC)執行印度洋大目鮪與黃鰭鮪魚種資源評估 ，進行印度洋大目鮪與黃鰭鮪 CPUE 標準化研究分析，並提出相關研究報告，以因應 2019 年國際漁業組織印度洋鮪類委員會(IOTC)熱帶鮪類資源指標更新評估。

本研究採用聚集分析處理標的魚種漁獲率的差異性議題，並利用決策樹探討各聚集所對應之作業策略的特徵。研究發現在熱帶區域，大目鮪、黃鰭鮪、其他魚類(油干)的漁獲量以及作業年代是主要判定聚集分類的因素，解釋度都接近七成。而東熱帶區域，作業策略是隨著不同的作業時期(年代)而有所改變。西熱帶區域的北部則會因緯度的高低，會有不同的作業策略。溫帶水域長鰭鮪、其他魚類(油干)、劍旗魚與南方黑鮪的漁獲量以及作業年代是主要判定聚集分類的因素，解釋度都高過七成。而西溫帶水域，作業策略是隨著不同的作業時期(年代)而有所改變，這個現象呼應了 2006 年油干漁業的發展。東溫帶水域隨著作業時期的改變，會有不同的作業策略，而且有幾艘特定的漁船有其獨特的作業策略。

五年來我國與日本、韓國與塞席爾科學家以及 IOTC 外聘獨立科學家共同探究印度洋熱帶鮪類標準化 CPUE 變動趨勢的合理估算方法，合作過程與成果已於五屆的 IOTC 熱帶鮪類工作小組會議中發表數篇研究報告，有助於印度洋熱帶鮪類資源利用狀態有更清楚的認識。因仍有許多疑慮待釐清，每年的國際合作均受國際漁業管理組織期待。

透過公開透明的國際合作，逐步提升對於漁獲統計資料的深度理解與運用，以期資源評估結果更具確定性。整體而言，除了透過深度的國際合作處理長久以來關於印度洋熱帶鮪類 CPUE 標準化序列趨勢不確定性的議題外，我國持續提供國際漁業組織我國漁業動態資訊對於我國的形象與漁業資源評估的可信度皆有所提升。

Abstract

The goals of the project include the analysis of Taiwanese tuna longline logbook data and observer data in the Indian Ocean and the standardization of CPUE series.

In this study, the clustering analysis was used to deal with the differences in the catch rate of the target species, and the decision tree was used to explore the characteristics of the operational strategies corresponding to each cluster. The study found that in the tropical region, the catches of the bigeyes, yellowfins, and other fish (oil dry) and the age of operation are the main factors determining the aggregation classification, and the interpretation degree is close to 70%. In the eastern tropical region, the operating strategy changes with different operating periods (ages). The northern part of the western tropical zone will have different operational strategies due to the latitude. The catches of albacore, other fish (oil dry), swordfish and southern blue tuna in temperate waters are the main factors determining the aggregation classification, and the interpretation degree is higher than 70%. In the West temperate waters, the operating strategy has changed with different operating periods (ages), which echoes the development of oil fisheries in 2006. The East temperate waters have different operational strategies as the study period changes, and several specific fishing boats have their own unique operational strategies.

The latest three years, the international collaborative work among Taiwanese, Japanese, Korean, Seychelles and IOTC scientists researched on the integrated standardized CPUE series and related issues. The collaboration is very productive. It provided a deeper understanding of the status of Indian tropical tuna. However, there are still many issues to be addressed. IOTC keep encouraging the international collaborative work to facilitate the tropical tuna stock assessment. Involved in the international collaborative work helps not only the quality of the stock assessment but also promoting Taiwan to be a responsible fishing country.

第一節　前言

自 1985 年後，印度洋大目鮪與黃鰭鮪一直都是台灣遠洋鮪延繩釣船隊在印度 洋主要利用之漁業資源。而印度洋大目鮪與黃鰭鮪資源狀態一直也是國際漁業組織 IOTC 關注的事項。以漁業利用強度與漁獲統計資料品質的角度而言 ，印度洋熱帶鮪類的資源評估工作非常倚賴延繩釣漁業的 CPUE 標準化序列指 標，因其可作為資源變動的指標。以往因臺灣與日本的 CPUE 標準化序列趨勢 存在無法解釋的差異，雖然在分析研究上，考慮了台灣和日本鮪延繩釣船隊 的作業型態，長年來包括標的魚種的移轉，作業空間的分布以及相關的歷史 變革。以近幾年來看，台灣一直以大目鮪為標的魚種，而日本則以黃鰭鮪為 標的魚種。且台灣的作業分布遍及印度洋大部分海域，而日本作業分布較為 侷限，百分之七十的黃鰭鮪漁獲量是來自於莫三比克海峽附近海域，所以若 大目鮪與黃鰭鮪資源評估只用日本的資料，會有代表性的問題。因此四年前 透過 IOTC、IOTC 外聘科學顧問以及台日以及韓塞席爾四國國際合作研究，整 合四國鮪延繩釣作業層級資料，估算整合性 CPUE 標準化序列以作為最佳資源 變動的指標。根據現階段合作結果認為，差異性主要源自於原始資料(名目漁 獲努力量，Nominal CPUE)的本質，而非資料處理或研究方法的變異。我國船 隊作業日誌回收率年間變化頗大，從 1979 年約 63%，到 1992 年，回收率最低 ，只有 4%。整體而言，1984 年到 2002 年回收率在五成以下，因過低的回收率 可能會降低作業日誌反映整個船隊作業概況的代表性。且檢視台日韓三國在 印度洋赤道海域年別每次作業大目鮪漁獲尾數的頻度分佈圖，在 1977~2001 年 以及 2005~2008 年年間，三國的分佈頗為相似。但在 1983~1991 年低漁獲(如每次作業捕獲 20 尾大目鮪)各國的變動幅度較大且不甚一致外，其中 2002~2004 年台灣的分佈模式異常，且和他國相比，平均而言，每次作業大目 鮪漁獲尾數高出許多。然而這四年台灣作業分佈似乎無明顯變化，推測此和 2002-2004 年我國大西洋與印度洋之間發生的洗魚事件有關，因此估算整合性 CPUE 標準化序列時，只取我國 2005 年(含)之後的作業日誌資料。目前大目鮪 與黃鰭鮪資源評估皆已採用延繩釣漁業整合 CPUE 標準化序列作為資源量變動 指標。但雖採用的延繩釣漁業整合性 CPUE 標準化序列，各國仍須分別提供各 國之 CPUE 標準化序列以綜合分析比較，每年檢視各國漁業發展現狀與 CPUE 序 列趨勢變化，持續以各種漁獲資料來源與分析監測資源狀態。

根據我國印度洋大型鮪延繩釣漁業之商業性漁獲統計資料，為估求更妥適的 標準化 CPUE 序列以反映資源量變動趨勢，必須考慮標的魚種、作業漁區、作 業策略等時空與作業船隻各個特徵的歷史變革。近期在檢視我國漁業作業特性的發展變化時，注意到每筐鉤數的大小有增加的趨勢。在我國的漁獲統計 系統中，每筐鉤數的紀錄始自 1995 年開始，某種程度而言，每筐鉤數的投放 鉤數反映了作業的標的魚種。以往的經驗與資料顯示，雖然每筐鉤數的大小 會因季節、漁區以及個別船隻其他作業漁具的規格而有所變化，但原則 ，若以大目鮪為標的魚種，每筐鉤數約會使用 15~18 鉤，而若以長期鮪為標的 魚種，每筐鉤數約會使用 12 鉤以下。而若觀察每筐鉤數的歷史時空分布，南 緯 15 度以北的熱帶海域，多數船隻以大目鮪為標的魚種，每筐鉤數較大，南 緯 15 度以南的溫帶海域，多數船隻以長鰭鮪為標的魚種，每筐鉤數較小，分 隔的非常明顯。然自 2010 末，有跡象顯示東南溫帶海域，每筐鉤數較歷年為 大，而 2010 年之後，

則整個印度洋海域，每筐鉤數呈現皆大幅增加的趨勢。 初步輔以來自業者與對外漁協的資訊，得知許多船隻改用美式滾筒，提升了 作業操作速度，所以每筐鉤數與總鉤數都會顯著增加。有鑑於此，漁具的變 革預期會影響我國船隊的漁捕效率，進而有可能會影響單位努力量漁獲量的 解析。因此本年度的研究重點設定在了解此一變革的發展現況，並探討此一 變革對於漁獲資料資訊解析的影像，以期 CPUE 序列趨勢的標準化得以適當進 行，以確保此資源量指標之代表性。

針對依據台灣商業性漁獲統計資料估得之印度洋黃鰭鮪與大目鮪的單位努力 漁獲量(Catch per unit effort, CPUE)標準化序列趨勢與日本的序列趨勢不 一致的議題，已於 2015 年開始進行了四年的國際合作研究。這四年進行了台 、日、韓與塞席爾各國漁業與漁業資料之概況與特性深度剖析，並考慮空間 、標的魚種與船隊漁獲能力等因子，分別估算各國印度洋大目鮪與黃鰭鮪魚 種標準化 CPUE 序列趨勢，以及整合各國資料後再估算標準化 CPUE 序列。主要 研究成果包括 1. 篩選有效之作業層級資料的條件設立會顯著影響後續 CPUE 標準化估算結果，建議篩選條件的設定必須審慎探究資料來源以及代表意義 ；2.CPUE 標準化模式因子的選用，五度方格漁區、標的魚種的選用指標與船 隊之漁撈能力等因子顯著影響 CPUE 變動趨勢的估算，建議後續應納入此些因 子進行 CPUE 標準化的分析；3.因我國印度洋鮪延繩船隊漁業活動之漁獲作業 日誌資料回收率於 2000 年前年間變化較大且部份年度回收率偏低，且 2002 年至 2004 年我國大西洋與印度洋之間發生的洗魚事件，檢視這四年漁獲作業日誌 ，整體船隊普遍漁獲表現異常，且根據現有資料無法進行有效辨別個別船隻 填報可信賴度，為確保整合 CPUE 標準化序列的適當性，因此只採用我國 2005 年後之漁獲作業日誌資料納入整合分析；4. 關於遠洋鮪延繩釣漁業或船 隊之漁撈能力 (fishing power) 一直是目前認為標準化 CPUE 序列趨勢若要用 來作為資源量變動指標是必要考慮的議題。我國印度洋鮪延繩釣漁船大目鮪 漁撈能力在核心區域從 1979 年的 0.9 些微增加至 2012 年的 1.1。 特別的是在南 印度洋海域在 1979 年至 2012 年年間從 0.7 明顯增至 1.4。 我國印度洋鮪延繩釣 漁船黃鰭鮪漁撈能力在核心區域從 1979 年的 0.7 些微增加至 1993 年的 1.0，之 後幾乎皆維持在穩定的水準。 而在南印度洋海域在 1979 年以及 1989 年有較高 的漁撈能力 1.2，在 1992 年以及 1993 年有較低的漁撈能力 0.6 外，其他年度至 1996 年都約為 1.0，自 1996 年後則持續增加至 2012 年的 1.3 年。整體而言，我 國印度洋鮪延繩釣漁船大目鮪與黃鰭鮪漁撈能力並不如預期得和日本一樣呈 現明顯上升趨勢，因此目前我國漁撈能力變異的機制尚無法掌握；5. 群集分 析法區別出我國印度洋鮪延繩釣漁業在各統計區的作業策略，也就是各組別 有其特有的漁獲組成、作業位置、作業季節、每筐鉤數等的分布特性。如在 西南印度洋統計漁區檢視出我國有明顯的油甘漁業於此，故後續進行大目鮪與黃鰭鮪的 CPUE 標準化時可以用群集組別效應或剔除油甘漁業資料估算更適當的 CPUE 標準化序列。

第二節　實施方法

2.1　台灣作業層級資料與漁業概況分析

本研究提請漁業署提供一度空間解析度航次原始作業日誌、觀察員資料、歷史 VMS 資料、漁獲統計書、核銷資料以及進出港資料。針對我國遠洋鮪延繩釣漁獲統計資料庫之漁獲努力量與各魚種漁獲量時間與空間分佈等項目資料進行深度檢視，以掌握漁業歷年發展動態。

2.2　聚集分析(Cluster Analysis)

因分析台灣印度洋鮪延繩釣漁業標的魚種黃鰭鮪與大目鮪的漁獲率時，若只考慮作業漁季、作業漁區以及漁獲組成等因子，而不考慮作業之標的魚種的移轉，並無法對於印度洋黃鰭鮪及大目鮪漁獲率的變異進行適當的掌握。 因此本研究利用聚集分析，根據每次作業或航次（船月別）漁獲組成的相似性進行分類，期能鑑別每次作業或航次的標的魚種，進而將組別視作為一目標魚種(或作業策略)的替代指標。 考慮以航次別作為一分析單位是因縱使標的魚種不變，時空變異之下，其漁獲組成的比例仍存有異質性。 因此預計以航次資料為一分析單位，進而設計分析架構，滿足組別內的變異程度小於組別間的變異，使聚集分析結果更具確適性。

因此考慮每次作業的魚種漁獲，包括黃鰭鮪、大目鮪、長鰭鮪、黑鮪、南方黑鮪、劍旗魚、旗魚類(黑皮旗魚、白皮旗魚、紅肉旗魚)、鯊魚以及其他魚類的漁獲組成。

此研究採用的方法主要參考 Bigelow and Hoyle(2012)以及 Winker *et al.* (2014)的研究方法。 首先去除無任何漁獲的作業紀錄，計算每筆作業紀錄各魚種漁獲尾數佔總漁獲尾數的百分比。 採用兩種資料處理方式進行聚集分析，第一種方式是將漁獲組成資料進行轉換以避免某些平均漁獲量較大的魚種會影響分析的有效性。轉換方式即是標準化常態分佈的過程。 而另一種方式即是不作任何資料轉換。

根據去年採用三種聚集分析方法的經驗，此次選用為 Ward hclust。 階層式聚集分析(hierarchical cluster analysis, Ward method)乃先利用統計分析軟體 R 的 dist 函數功能計算資料結構異質性的距離，然後再用 hclust 函數功能，給定參數 Ward.D 進行分析。

一般而言，聚集組別的選定頗為主觀。 本研究根據漁業實況，判定至少會有兩種不同作業策略存在於船隊中，一是以大目鮪為標的魚種，二是以長鰭鮪為標的魚種。 組別選定會參考不同的統計分析結果。

2.3　分類與迴歸樹(Classification and regression tree, CART)模式建立分析各群組的作業策略

現存的統計分類方法眾多，分類與迴歸樹(CART)演算法適用於歸納分析具複雜且龐大變數的資料集。因基本演算概念是以二元分割規則將資料分類，而分類過程與樹狀結構相似，擁有根、節以及樹葉等結構，因此 CART 演算法又被稱為決策樹(Decision tree)。在演算過程中產生一連串的規則，而演算結果可用來預測樣本其歸納出的類別所在。 目前有許多與ＣＡＲＴ 類似且更複雜整合性的機器

學習演算法(Machine Learning Algorithm)被發展出來克服原有演算法的障礙和缺陷，且多有現成開放免費的 R 套裝軟體可利用，如 ‘dismo’以及‘gbm’等 R 套件。擬採用提升決策樹(Boosting Regression Tree)模式分析，並與傳統的 CART 所建立的模式比較。

混淆矩陣是對有監督學習分類算法準確率進行評估的工具。通過將模型預測的數據與測試數據進行對比，使用準確率，覆蓋率和命中率等指標對模型的分類效果進行度量。

根據大目鮪的 RegB3 漁區定義，將印度洋劃分為五個區，分別針對各區域，使用決策樹進行分類預測，並使用混沌矩陣對預測模型的準確率進行評估。首先我們將所有作業日誌漁獲資料分為兩組，第一組為訓練集，占所有數據的 80%，我們通過訓練集的數據計算參數並生成模型。第二組數據為測試集，占所有數據的 20%。我們使用測試集的數據對模型的分類結果進行測試，並使用混淆矩陣對測試結果進行評估。模型的準確率數據就是根據 Positive(正)和 Negative(負)相互交叉的 4 組數據計算得出。

betreg5bigml | Training (80%) vs. betreg5bigml | Test (20%)				True positive		False positive	
ACTUAL VS. PREDICTED				True negative		False negative	
Threshold: 50%							
	Positive	Negative Classe	ACTUAL	RECALL		F	Phi
Positive	1668	2704	4372	38.15%		0.4936	0.4779
Negative Classes	718	36618	37336	98.08%		0.9554	0.4779
PREDICTED	2386	39322	41708	68.11%		0.724498671	0.47786463
PRECISION	69.91%	93.12%	81.52%	91.80%			
						Powered By BigML	

True Positive 簡稱 TP，表示測試集中是 Positive，模型預測結果是 Positive 的數據條目。

False Positive 簡稱 FP，表示測試集中是 Negative，模型預測結果是 Positive 的數據條目。

False Negative 簡稱 FN，表示測試集中是 Positive，模型預測結果是 Negative 的數據條目。

True Negative 簡稱 TN，表示測試集中是 Negative，模型預測結果是 Negative 的數據條目。

Sensitivity 又稱為 Recall，簡稱 TPR，表示模型正確預測 Positive 在測試集中所有 Positive 的比率。

Specificity 簡稱 SPC，表示模型正確預測 Negative 在測試集中所有 Negative 的比率。Positive Predictive Value 簡稱 PPV，表示模型正確識別 Positive 的比率。

Negative Predictive Value 簡稱 NPV，表示模型正確識別 Negative 的比率。

Accuracy 簡稱 ACC，表示模型正確預測 Positive 和 Negative 的比率。

2.4 泛線性模式（Generalized Linear Model, GLM）

分別針對大目鮪與黃鰭鮪區依同質性原則，將印度洋劃分成數個統計漁區，分魚種分區分別進行單位努力漁獲量標準化研究，利用泛線性模式估計台灣鮪延繩釣漁業利用印度洋大目鮪與黃鰭鮪單位努力漁獲量標準化變動趨勢部分採用的基本模式是以時間(年季)、五度方格空間、漁船以及作業策略(標的魚種)組別為主要因子。並進一步分析模式殘差分佈，再針對各可能的時空交互因子、多種

殘差機率分佈假設或嘗試與泛線性模式的各類變異擴充模式進行模式修正嘗試，以達最佳模式套適效果，估計最適資源量變動指標。並配合提供印度洋鮪類委員會(IOTC)執行大目鮪與黃鰭鮪資源評估，提出相關研究報告。

第三節　結果與討論

3.1　台灣鮪延繩釣漁業印度洋大目鮪與黃鰭鮪相關作業現況

美式滾筒(高速捲線器 reel)為美國延繩釣漁業漁具之一，根據對外漁協至東港小釣船訪查，多數小釣船都已有美式滾筒的漁具設備。早期台灣小釣船採手動式或傳統式捲線器，每次作業鉤數較少。採美式滾筒後，每次作業鉤數可達 2000 鉤以上，因自動化流程加速作業效率。因為大釣漁船考慮成本效益、主繩長度、美式滾筒的安裝，相關機組件需調整，有許多綜合的考量。根據台灣鮪魚公會取得的資料顯示，新船 CT5 CT6 多採用美式滾筒。而 CT7 大船整體成本效益考量，不一定採用美式滾筒。

鐵殼船(CT7)，船員最多約 30 人)，汰建塑鋼船(fob)(CT5&6，船員最多約 25 人)(最重 350 公噸)，成本(油價、人力)考量，一艘船賺四千萬打平，若改成塑鋼船較輕，成本省上 500 萬至 1 千萬。汰建為塑鋼船時，會考慮採用美式滾筒(仿東港小釣船)，此時作業模式每筐鉤數增加多捉一些浮水魚，所以漁獲組成應會有所不同，黃鰭鮪的比例推測會較高，之前根據經驗，估計可能大目鮪比黃鰭鮪約 7:3 或 8:2。但是塑鋼船怕撞不夠堅固易漏油。目前印度洋，鐵殼船約占 2/3，塑鋼船約占 1/3，大西洋和太平洋則約(3:1=鐵殼船:塑鋼船)。但公會不須提供到漁具資料給漁業署，也就是說漁業署目前很可能沒有美式滾筒的相關資訊。

根據資料分析顯示(圖 15~圖 17)，2014 年之前後，在熱帶海域各頓級別，利用大於等於 15 的每筐鉤數作業，漁獲組成的變化黃鰭鮪的比較在 CT5 與 CT6 的作業漁獲組成是有小幅增加的現象，CT7 卻有減少現象，頗為符合業者的作業現況。

利用 IOTC-CPUE 工作小組畫分之大目鮪漁區進行分區分年比較觀察員與作業報表大目鮪體長累積頻度圖之差異。針對印度洋大目鮪體長資料問題，經檢視作業報表量測之大目鮪體長資料與觀察員資料之差異性結果(如圖 20~圖 22)，本次利用觀察員檢核法篩出歷年品質較佳之觀察員航次資料共有 172 航次 7 萬多筆體長資料(第一區約佔 56%，第二區約佔 18%，第三區約佔 10%及第四區約佔 9%)，後續進行各區兩類體長資料之適合度檢定及體長頻度檢視，檢定結果皆顯示兩類資料是呈現不一致情況，此外，大目鮪體長亦是有以固定數加重量填報的問題，此外，利用觀察員體長體重關係式套入 2009-2017 年作業報表之量測體重以重新估算體長資料，但在第一區似乎轉換後之體長仍是與觀察員趨勢有差異，而經協會進一步以單船檢視方式估算第一區各船兩條累積頻度圖的差異值，發現差異值在小於 0.03 的兩條累積頻度圖似乎較為一致，後續在以此標準篩選作業船，則作業報表與觀察員的累積頻度圖就會趨於一致，但資料會從原本的 1,262,639 筆降至 1,66,235 筆，僅保留 10%資料，故目前針對大目鮪體長部分仍是建議 IOTC 以觀察員量測資料取代作業報表進行資源評估

針對第一區的兩類資料中(觀察員頻度相似的船隊跟不相似的船隊)，各挑出前三艘船繪製分布圖與體長頻度圖，以及索馬利亞海盜區域之體長頻度圖(東經 35-65/南緯 5 度以北)。結果顯示觀察員頻度相似的這三艘船其分布均明顯偏東，且其體長頻度圖也偏小。

3.2　印度洋大目鮪與黃鰭鮪資源狀況與各國漁業利用概況

關於大目鮪物種漁業概況，近四年(2014~2017)，主要的利用漁業為超低溫和

生鮮延繩釣漁業與圍網，佔總大目鮪漁獲量七成。超低溫和生鮮延繩釣漁業漁獲量從在 2014 年佔總漁獲量的一半，逐年下降至 2017 年約四成不到，而圍網漁獲量逐年增加至 2017 年約佔三成。其他相對較重要的漁業為沿近海延繩釣漁業與小型圍網漁業。另近幾年斯里蘭卡和伊朗的刺網漁業持續發展，漁獲量呈增加的趨勢。主要船隊依次為印尼(延繩釣與圍網)、台灣(延繩釣)、塞席爾(延繩釣與圍網)和歐盟西班牙(圍網)。印度洋大目鮪年總漁獲量從 1970 年代的兩萬公噸開始，因 1980 年歐盟圍網加入，於 1990 年增加至約 15 萬公噸，後因海盜活動等原因漁獲量下降至最近幾年約為 10 萬公噸。

關於黃鰭鮪物種漁業概況，1980 年後，家計型漁業逐漸發展，近五年(2013~2017)，商業型漁業和家計型漁業漁獲量各佔一半，各約為 20 萬公噸。主要船隊依次為歐盟西班牙(圍網)、馬爾地夫(手釣與一桿釣)、伊朗(刺網)、塞席爾(圍網)與斯里蘭卡(刺網與沿岸延繩釣)。印度洋黃鰭鮪年總漁獲量於 1950 至 1980 年早期維持在約七萬公噸的水準，到 1993 年，因為圍網與延繩釣漁業的加入，漁獲量增加至約 40 萬公噸，2003 年和 2006 年年漁獲量高達 50 多萬公噸。2007 至 2009 年因海盜活動，許多船隊作業漁場東移或南移，漁獲量下降至 2004 年漁獲水準的六成，但 2012 年後又恢復至約 40 萬公噸。近五年平均每年印度洋黃鰭鮪總漁獲量約 41 萬公噸，而目前階段的漁獲仍超過 40 萬公噸。

依據印度洋鮪類管理委員會 2018 年第 20 屆熱帶鮪類工作小組之會議報告(cite)以及印度洋鮪類管理委員會 2018 年第 21 屆科學委員會之會議報告，目前國際漁業組織管理情形，2018 年未做全面性完整評估。根據 2016 年印度洋大目鮪的資源評估結果認為此資源尚未面臨過渡捕撈(overfishing)，且未達過漁狀態(overfished)。各種資源評估模式分析結果皆顯示大目鮪目前資源量並未過漁，且亦未處於過漁狀態，然而目前大目鮪最大持續生產量(MSY)點估計為 10 萬四千噸，但是綜合各種資源模式評估結果可能範圍區間分布頗大，約介於 87,000~121,000 噸之間。2015 年親魚量估計約為初始親魚量的 38%，且為可供給最大持續生產量的親魚量之 129%。相對於 2013 年的資源評估結果，生物量略微下降(from 144 to 129% SB/SBMSY)以及漁業壓力略為增加(from 42 to 76% F/FMSY)。近五年平均年漁獲量約為九萬六千公噸，2017 年大目鮪總漁獲量約為九萬公噸，皆未超過 MSY 水準。輔以 2018 年的各種資源量指標資訊，判定大目鮪資源目前仍處於未過漁，且亦未處於過漁狀態。

黃鰭鮪的資源狀態評估進展是 2015 年黃鰭鮪評估結果為已面臨過渡捕撈(overfishing)，且達過漁狀態(overfished)。2018 年再次進行黃鰭鮪資源評估，資源狀況仍處於紅字警戒，雖然機率為 94%，因此此資源仍面臨過渡捕撈(overfishing)，且達過漁狀態(overfished)。最大持續生產量估計值約 40 萬公噸。2017 年親魚量估計約為初始親魚量的 30%，且為可供給最大持續生產量的親魚量之 83%。資源評估結果顯示，親魚量仍過低(SB/SBMSY=0.83)以及漁業壓力仍過高(F/FMSY=1.2)。輔以 2018 年的各種資源量指標資訊，判定黃鰭鮪資源仍面臨過渡捕撈(overfishing)，且達過漁狀態(overfished)。

大目鮪物種管理狀態簡述如下: 自 2007 年後延繩釣努力量顯著減少，漁獲壓力減低。2016 年進行風險評估，估計若維持在目前的漁獲量水準(九萬公噸以內)，以最大持續生產量為基準的參考點為判斷依準，2018 年和 2025 年資源狀態應該可以維持穩健狀態。資源可能避免面臨過漁狀態。若在努力量持續下降，且漁獲量持續低於 MSY 水準下，則就不需要有立即性的管理措施，但仍需加強對於資料收集及分析，以降低評估的不確定性。

黃鰭鮪物種管理狀態簡述如下: 鑒於資源狀態不佳，近幾年漁獲量又居高不下，估計這幾年的補充量又低，所以目前進行暫時性復育計畫 Resolution 17/01 取代 Resolution 16/01，並且限制漁獲量維持在 2014/2015 年的漁獲水準以下。2017 年已有管理措施即將施行，我國印度洋鮪延繩釣漁業的漁獲量必須管控在 2014 年漁獲水準的 90%。目前 IOTC 統計資料數據顯示，各漁業國黃鰭鮪管理 18/02 遵守情形，商業船隊都還算遵守，但是許多沿岸國的黃鰭鮪漁獲量都超過允許的配額量，整理而言，總漁獲量並未如期控管，甚至較去年都還高，現行的管理措施未奏效。

3.3 聚集分析結果

表 4 顯示分別依據大目鮪新漁區定義，各區域聚集分析方法的結果。以大目鮪(RegB3)漁區定義第一區域為例，方法 hcltrip 結果清楚顯示聚集一，主要目標魚種為長鰭鮪與黃鰭鮪，次要魚種為大目鮪；聚集二，主要目標魚種包括大目鮪與黃鰭鮪，次之為劍旗魚；聚集三，主要目標魚種包括大目鮪，次之為黃鰭鮪；聚集四，主要目標魚種大目鮪與其他魚種，次之為黃鰭鮪；聚集五，主要目標魚種包括黃鰭鮪與大目鮪。圖 33 至圖 56 呈現各區域內各聚集作業特性、作業空間分佈以及漁獲組成特性，各聚集的作業空間分佈相對於其他特徵呈現比較明顯的區隔。

以大目鮪(RegB3)漁區定義第一區域為例(圖 33)，各類統計分析結果顯示將作業資料分成五個聚集群組為最佳。而圖 41 顯示以大目鮪(RegB3)漁區定義第三區域為例，各聚集群組內的作業特徵。如第四類聚集群組應對應的是自 2005 年後以油魚為標的魚種的作業紀錄，而第一類聚集群組則對應的是以長鰭鮪為標的魚種的作業紀錄，而第三類聚集群組則對應的是以大目鮪與黃鰭鮪為標的魚種的作業紀錄。我國作業日誌已經從 2009 後有獨立紀錄油魚漁獲，本研究根據此資訊可確認聚集分析在缺乏獨立油魚漁獲紀錄的往年，仍可以根據漁獲組成以聚集分析成功隔離出油魚漁業，並將此類作業努力量剔除於熱帶鮪類 CPUE 標準化的分析研究。

3.4 決策樹分析結果

圖 57 至圖 76 顯示大目鮪(RegB3 漁區定義)各區域決策樹、重要解釋因子與混淆矩陣。熱帶區域大目鮪、黃鰭鮪、其他魚類(油干)的漁獲量以及作業年代是主要判定聚集分類的因素，解釋度都接近七成。而東熱帶區域，作業策略是隨著不同的作業時期(年代)而有所改變。西熱帶區域的北部則會因緯度的高低，會有不同的作業策略。溫帶水域長鰭鮪、其他魚類(油干)、劍旗魚與南方黑鮪的漁獲量以及作業年代是主要判定聚集分類的因素，解釋度都高過七成。而西溫帶水域，作業策略是隨著不同的作業時期(年代)而有所改變，這個現象呼應了 2006 年油干漁業的發展。東溫帶水域隨著作業時期的改變，會有不同的作業策略，而且有幾艘特定的漁船有其獨特的作業策略。

3.5 CPUE 結果

根據 Constant Lognormal GLM 的分析結果，由表 6 至表 15 各大目鮪與黃鰭鮪漁區的 Anova 統計表與標準化模式 R^2 來看，年季時間、五度經緯度方格空間因子、作業鉤數、漁船與作業策略對於漁獲率皆有明顯的統計解釋意義。R^2 的值分布在 0.42 至 0.68 之間，顯示模式納入的所有因子對於漁獲率的變動有一定的

解釋程度。若以 CPUE 序列趨勢的解釋力與影響力之統計分析亦也可了解各因子的重要性。簡單來說，由影響力分析可以了解名目 CPUE 序列與標準化 CPUE 序列的差異主要是來自於哪一個主要因子的影響。 隨然某個因子可以解釋很大的 CPUE 值的變異，但是加入此因子並不一定會有明顯的校正效果。原因是可能每年這個因子的實際變數值分布會很類似，舉例來說，季節或許可以解釋很大程度 CPUE 的變異，然每年作業努力量在各季節的作業分布可能很類似，因此模式校正後，名目 CPUE 序列與標準化 CPUE 序列的差異並不顯著。舉大目鮪區域 1N 的影響力分析結果為例，各漁船的模式估計係數變化頗大，也就是有些船的單位努力漁獲量明顯高出許多，而許多高效能船隻在某些年佔較高的比例，如 1979 年，則就導致那一年的名目 CPUE 的值就會較高，而經過納入漁船效應的模式標準化後，1979 年標準化 CPUE 的值就會明顯下降。

仍以大目鮪區域 1N 的影響力分析結果為例，每年作業努力量的空間分布可算是相當穩定，但在 2009 年開始在索馬利亞海域有活躍的海盜活動，所以之後三年，分布在索馬利亞海域的作業明顯下降，而 2012 年許多漁船返回這高大目鮪漁獲率的區域作業，所以在 2012 年則有五度方格空間因子的年影響力就非常高。圖 80 與圖 83 顯示台灣漁船在大目鮪區域 1S 與區域 4 的捕獲大目鮪的漁獲能力有助年上升的趨勢，但在其他區域則無明顯變化趨勢。圖 87 顯示台灣漁船在黃鰭鮪區域 4 的捕獲黃鰭鮪的漁獲能力有助年上升的趨勢，但在其他區域則無明顯變化趨勢。

圖 89 至圖 90 顯示各區域大目鮪與黃鰭鮪標準化 CPUE 序列趨勢國際合作分析結果與本研究之比較圖，整體長期變化趨勢頗為一致。根據各魚種各區域本研究以及四國整合 CPUE 序列趨勢比較，在熱帶海域，我國黃鰭鮪的 CPUE 序列趨勢較國際合作分析結果而言，下降的幅度稍微有所緩和。

大目鮪區域 1N 以及區域 1S 這個西熱帶區域的資源量指標趨勢顯示，1979 年至今，並沒有明顯變化趨勢，然自 2012 年之後，最近五年呈現逐年下降的短期趨勢。而在溫帶區域，1979 年至今，CPUE 序列也並沒有明顯變化趨勢，然最近兩年呈現相對較低的值。

黃鰭鮪在西熱帶區域的資源量指標趨勢顯示，1979 年 CPUE 逐年增加至 1987 年後，上下震盪至 2006 年，2006 年之後則一直下滑至 2010 年，2012 年上升至相對高點，但之後至今下降至長期來看相對低點，黃鰭鮪在東熱帶區域的資源量指標趨勢顯示，1989 年 CPUE 逐年緩慢下降至 2006 年，但呈現劇烈下降至 2016 上的長期來看相對低點，呼應目前黃鰭鮪資源評估為過漁的紅色警戒狀態。黃鰭鮪在西部溫帶區域的資源量指標趨勢顯示，1979 年 CPUE 逐年下降至 2011 年後，至今上下震盪。黃鰭鮪在東部溫帶區域的資源量指標趨勢顯示，今年給予較嚴格的樣本代表性標準，所以樣本數較少，有許多缺失值，不易比較。

圖 91 至圖 92 顯示標準化模式套適殘差分析統計圖，有幾個模式殘差分布等相關檢視與常態分佈的假設頗有差距，發現大目鮪較適合用 constant lognormal model，而黃鰭鮪較適合用 delta lognormal model。應該是大目鮪是我國延繩釣的主要標的魚種，而黃鰭鮪較屬於混獲魚種。

圖 93 至圖 102 顯示大目鮪與黃鰭鮪各區域與各聚集 CPUE 標準化模式殘差中位數年度分布、CPUE 標準化模式殘差年度分布與空間分布。從圖 93 發現在熱帶區域北部以大目鮪為主要標的魚種的作業船隻大目鮪漁獲率近五年某些季節漁獲率表現比往年高許多。整體來看近五年的漁獲率亦稍高，但是並無明顯的分間分布。從圖 100 發現在西部溫帶區域，整體而言，黃鰭鮪漁獲率有較明顯的空間分布，在莫三比克水域的黃鰭鮪的漁獲率較高。

第四節　檢討與建議

因應印度洋鮪類保育組織 IOTC 管理期程，我國應於今年八月中旬提供大目鮪標準化 CPUE 序列以作為資源量指標之一，以利資源評估。

近年我國延繩釣業者一直對於IOTC大目鮪與黃鰭鮪資源評估結果與現況不符產生質疑，而國外圍網業者亦透露出相同的質疑，並認為資源評估模型中之 CPUE 序列可能因忽略丟棄量而導致評估結果出現偏誤，尤其在進行漁獲量管制後，丟棄量的影響必定提高。而這也開始促始 IOTC 關注延繩釣船丟棄量的議題，且今年聯合 CPUE 分析已開始將丟棄量納入模型中進行校正，故後續需持續關注是否將對先前資源評估結果進行修正，尤其是在黃鰭鮪的資源評估上。

2017-2018 年我國黃鰭鮪丟棄量比例相較歷年明顯上升，但我國整體大目鮪與黃鰭鮪丟棄量比例仍是處於偏低狀態，雖然目前 IOTC 尚未要求我國提交丟棄量資料，但現階段已開始嘗試將丟棄量納入 CPUE 標準化分析中，因此未來對於丟棄量資料收集將顯得重要，建議後續應加強對業者宣傳丟棄量回報之重要性，以期提升我國丟棄量回報之比例。

第五節　成果效益說明及重大突破

5.1　學術成就、技術創新、經濟效益、社會影響

五來我國與日本、韓國與塞席爾科學家以及 IOTC 外聘獨立科學家共同探究印度洋熱帶鮪類標準化 CPUE 變動趨勢的合理估算方法，合作過程與成果已於五屆 IOTC 熱帶鮪類工作小組會議中發表數篇研究報告，有助於印度洋熱帶鮪類資源利用狀態有更清楚的認識。因仍有許多疑慮待釐清，每年的國際合作均受國際漁業管理組織期待。 透過公開透明的國際合作，逐步提升對於漁獲統計資料的深度理解與運用，以期資源評估結果更具確定性。整體而言，除了透過深度的國際合作處理長久以來關於印度洋熱帶鮪類 CPUE 標準化序列趨勢不確定性的議題外，我國持續提供國際漁業組織我國漁業動態資訊對於我國的形象與漁業資源評估的可信度皆有所提升。

參考文獻

Bigelow, k. and Hoyle, S.D., 2012. Standardized CPUE for South Pacific Albacore, WCPFC-SC8, Busan, Republic of Korea.

Chang, S.-K., Hoyle, S. and Liu, H.-I., 2011. Catch rate standardization for yellowfin tuna (Thunnus albacares) in Taiwan's distant-water longline fishery in the Western and Central Pacific
Ocean, with consideration of target change. Fisheries Research, 107(1-3): 210-220.

He, X., Bigelow, K.A. and Boggs, C.H., 1997. Cluster analysis of longline sets and fishing strategies within the Hawaii-based fishery. Fisheries Research, 31(1-2): 147-158.

Hoyle, S.D., 2014. Spatial considerations in bigeye and yellowfin CPUE from Japanese and Taiwan,China longline fisheries in the Indian Ocean, IOTC WPTT16, Bali, Indonesia.

Hoyle, S.D., Langley, A.D. and Campbell, R.A., 2014. Recommended approaches for standardizing CPUE data from pelgic fisheries, WCPFCSC10, Majuro, Republic of the Marshall Islands.

Hoyle SD, Okamoto H, Yeh Y-M, Kim ZG, Lee SI &Sharma R, 2015. Report of the 2nd CPUE Workshop on Longline Fisheries, 30 April – 2 May 2015, IOTC WPTT17. Montpellier, France.Hoyle SD, Yeh Y-M, Chang S-T &Wu R-F, 2015. Descriptive analyses of the Taiwanese Indian Ocean longline fishery, focusing on tropical areas. IOTC WPTT17 Montpellier, France.Hoyle SD, Doo Nam Kim, Sung Il Lee, Takayuki Matsumoto, Kaisuke Satoh, and Yu-Min Yeh. 2016. Collaborative study of tropical tuna CPUE from multiple Indian Ocean longline fleets in
2016. IOTC-2016-WPTT18-14.

Hoyle SD, et al. 2017. Collaborative study of tropical tuna CPUE from multiple Indian Ocean longline fleets in 2017. IOTC-WPTT19-32, Victoria, Seychelles.

Hoyle SD, Satoh K and Matsumoto T. 2017. Exploring possible causes of historical discontinuities in Japanese longline CPUE. IOTC-WPTT19-33, Victoria, Seychelles.

Hoyle SD, Satoh K and Matsumoto T. 2017. Selectivity changes and spatial size patterns of bigeye and yellowfin tuna in the early years of the Japanese longline fishery. IOTC-WPTT19-34, Victoria,
Seychelles.

Hoyle SD, Satoh K and Matsumoto T. 2017. Exploration of Japanese size data and historical changes in data management. IOTC-WPTT19-35, Victoria, Seychelles.

Hoyle SD. 2017. Regional scaling factors for Indian Ocean stock assessments. IOTC-WPTT19-36, Victoria, Seychelles.IOTC, 2014. Report of the Seventeenth Session of the IOTC Scientific Committee, IOTC SC17, Seychelles.

Matsumoto T, et al. 2017. Consideration on high jump of Japanese longline CPUE for bigeye and yellowfin tuna in the late 1970s in the Indian Ocean. IOTC-2017-WPTT19-26.

Maunder, Mark N., John R. sibert, Alain Fonteneau, John Hampton, Pierre Kleiber, and Shelton J. Harley. 2006. Interpreting catch per unit effort data to assess the status of individual stocks and communities. ICES Journal of Marine Science, 63: 1373-1385.

Okamoto, H., 2014a. CPUE of bigeye and yellowfin tuna caught by Japanese longliner in the Indian Ocean standardized by GLM considering several aspects of area, catchability and data resolution, IOTC WPTT16, Bali.

Okamoto, H., 2014b. Provisional study on comparison of CPUE trend of bigeye and

yellowfin tuna between Japanese and Taiwan-China longline fisheries based on whole and shared strata in the Indian Ocean, IOTC WPTT16, Bali, Indonesia.
Okamoto, S.D.H.a.H., 2011. Analyses of Japanese longline operational catch and effort for bigeye and yellowfin tuna in the WCPO, WCPFCSC7-2011/SA IP-01,
Pohnpei, Federated States of Micronesia. Sofia Ortega-Garcia, Daniel Lluch-Belda and Pablo Arenas Fuentes. 2003. Spatial, seasonal, and annual fluctuations in relative abundance of yellowfin tuna in the eastern Pacific Ocean during 1984–1990 based on fishery CPUE analysis. Bulletin of marine science, 72(3):613-628.
Yeh, Y.-M., 2014. Analysis of Taiwanese longline fisheries based on operational catch and effort data for bigeye and yellowfin tuna in the Indian Ocean, IOTC WPTT16, Bali, Indonesia.
Yeh Y-M &Chang S-T, 2015. Updated CPUE standardizations for bigeyeand yellowfin tuna caught by Taiwanese longline fishery in the Indian Ocean using generalized linear model. IOTC-WPTT17,
Montpellier, France.
Yeh Y-M &Chang S-T, 2016. Updated CPUE standardizations for bigeye and yellowfin tuna caught by Taiwanese longline fishery in the Indian Ocean using generalized linear model. IOTC-WPTT18, Victoria, Seychelles.
Yeh Y-M, Hoyle S and Chang S-T. 2017. Updated CPUE standardizations for bigeye and yellowfin tuna caught by Taiwanese longline fishery in the Indian Ocean, using Generalized Liner Model. IOTC-WPTT19-31, Victoria, Seychelles.
Winker, H., S. E. Kerwath and C. G. Attwood (2014). "Proof of concept for a novel procedure to standardize multispecies catch and effort data." Fisheries Research 155: 149-159.

備註：限於篇幅，省略附件之圖表。

附件 4

Global Ecology and Conservation 62 (2025) e03752

Contents lists available at ScienceDirect

Global Ecology and Conservation

journal homepage: www.elsevier.com/locate/gecco

ELSEVIER

Original research article

Best practices for mitigating seabird bycatch on Taiwanese albacore longline fishing vessels operating in the southeastern Atlantic Ocean

Hsiang-Wen Huang [a], Huan-Chang Liao [b], Ting-Chun Kuo [a], Shu-Chun Chen [c], Yu-Min Yeh [d,*]

[a] *Institute of Marine Affairs and Resource Management, National Taiwan Ocean University, Keelung, Taiwan*
[b] *Overseas Fisheries Development Council of the Republic of China, Taiwan*
[c] *Institute of Statistical Science, Academia Sinica, Taiwan*
[d] *Department of Tourism Management, Nanhua University, Chiayi County, Taiwan*

A R T I C L E I N F O

Keywords:
Seabird bycatch
Longline fishery
Albacore
Mitigation measures
Bird-scaring line
Weighted branch line

A B S T R A C T

Seabird bycatch—particularly involving albatrosses and petrels—remains a significant conservation concern in pelagic longline fisheries. This study evaluated the effectiveness of three mitigation measures—bird-scaring lines (BSLs), weighted branch lines, and night setting—in reducing seabird bycatch in the Taiwanese albacore (Thunnus alalunga) longline fishery operating in the southeastern Atlantic Ocean. Observations were conducted aboard a commercial vessel during 103 longline sets in 2013. Four BSL treatments were tested: single and double conventional BSLs and single and double experimental BSLs recommended by the International Commission for the Conservation of Atlantic Tunas (ICCAT), each combined with either weighted (60 g at 3 m from the hook) or unweighted branch lines. A total of 298 seabirds were caught during line setting, with an additional 18 birds caught and released alive during hauling and trolling. Night setting emerged as the most effective mitigation measure, with a bycatch rate of 0.046 birds per 1000 hooks—substantially lower than the 1.101 birds per 1000 hooks recorded during daytime setting. While BSLs effectively deterred seabird attacks within their aerial extent, their efficacy declined when baited hooks remained within the diving range of seabirds beyond this zone. Weighted branch lines reduced seabird bycatch by 61 %; however, they were also associated with a potential decrease in albacore catch rates. Our findings highlight that the effectiveness of best practice mitigation—namely, the combined use of BSLs and weighted branch lines—depends on ensuring that baited hooks reach depths beyond seabird diving capabilities before exiting the aerial extent of the BSLs. Further optimization is needed to balance conservation outcomes with fishery performance.

1. Introduction

Many seabirds face significant threats from human activities at sea (Melvin et al., 2023; Votier et al., 2023). Among all the threats, fisheries bycatch poses one of the most severe risks, particularly for species with large body sizes, slow reproductive rates, specialized

* Correspondence to: 55 Section 1, Nanhua Rd, Dalin Township, Chiayi County 622301, Taiwan.
E-mail address: ymyeh@nhu.edu.tw (Y.-M. Yeh).

https://doi.org/10.1016/j.gecco.2025.e03752
Received 1 January 2025; Received in revised form 22 June 2025; Accepted 13 July 2025
Available online 17 July 2025

diet and distinct foraging behaviors, such as albatrosses and petrels within the Procellariiformes (Jimenez et al., 2010, 2011; Richards et al., 2024, 2020; Robertson et al., 2006; Seco Pon et al., 2007). The impact of fisheries on seabird conservation has been widely studied across various spatiotemporal dimensions and seabird species (Collins et al., 2021; Li et al., 2016; Votier et al., 2023), with bycatch rates commonly used as a key metric to evaluate these effects (Lewison et al., 2004). Currently, seabird bycatch rates are primarily determined by four factors: overlap between seabird and fishery distributions, fishing gear configuration, seabird behaviors, and seabird abundance (Anderson et al., 2011; Huang and Yeh, 2011; Jiménez et al., 2020).

Although multiple factors influence seabird bycatch, their effects can vary widely depending on how they interact in specific ecological and fishing operational context. While spatial overlap between seabirds and fisheries plays a crucial role in determining bycatch rates (Calado et al., 2021; Jiménez et al., 2020), changes in fishing gear configuration can significantly reduce seabird bycatch risks (Oliveira et al., 2015). Studies have demonstrated that modifying gear design and fishing operations to reduce seabird access to bait can markedly decrease bycatch (Melvin et al., 2013, 1999). Seabird behavior also strongly affects bycatch rates. For example, white-chinned petrels (*Procellaria aequinoctialis*) aggressively compete for bait, offal, and discards, leading to high bycatch rates in the Southern Ocean longline fisheries (Weimerskirch et al., 2000). In contrast, white-bellied storm petrels (*Fregetta grallaria*) and black-bellied storm petrels (*Fregetta tropica*) frequently attend longline vessels but rarely attack bait, leading to low bycatch rates (Bugoni et al., 2008). From the perspective of seabird abundance, fisheries with a high likelihood of bycatching endangered species require specific regulations (Geernaert, 1999).

With one of the largest distant-water fishing fleets in the world, Taiwan has implemented various mitigation measures to reduce seabird bycatch in its high-seas longline fisheries, in line with international conservation efforts and recommendations from Regional Fisheries Management Organizations (RFMOs). In support of these efforts, Taiwan established its National Plan of Action for Reducing the Incidental Catch of Seabirds in Longline Fisheries (NPOA-Seabirds) in 2014 (Fisheries Agency, 2014). These measures aim to minimize interactions between seabirds and longline fisheries, thereby promoting seabird conservation and reducing bait loss (FAO, 1999). These measures can be categorized as those that prevent seabirds from seeing bait and those that render baited hooks inaccessible. Measures that reduce bait visibility include discarding offal on the opposite side of baited hooks to distract seabirds, and setting longlines at night (Gilman et al., 2008). Measures that render baited hooks inaccessible include installing a hook-shielding device, deploying bird-scaring lines (BSLs) and using weighted branch lines to increase the sink rate of baited hooks beyond the reach of seabirds (Melvin et al., 2014). Among those measures, the simultaneous use of BSLs, weighted branch lines, and night setting are recommended best practice by the Agreement on the Conservation of Albatrosses and Petrels (ACAP) (ACAP, 2024). All five tuna RFMOs have adopted seabird conservation measures that require vessels operating in areas overlapping with seabirds to implement a combination of mitigation measures selected from approved options.

BSLs are streamers that hang from a line attached at a high point near the stern of a fishing vessel, creating a barrier to prevent seabirds from accessing baited hooks (Løkkeborg, 2003). Evidence suggests that BSLs are particularly effective in regions with less diverse seabird assemblages that are dominated by shallow-diving albatrosses (Melvin et al., 2014; Sato et al., 2013). However, they are less effective in regions where seabirds exhibit greater diving abilities (Baker and Wise, 2005). The effectiveness of BSLs is also influenced by gear configuration and fishing operations (Melvin et al., 2014; Yokota et al., 2008). To optimize the aerial coverage of BSLs, adjustments can be made to the height of the tori pole, the length and material of the main line, the towed object (to prevent tangling), and the arrangement of streamers (Melvin et al., 2004; Proceedings of the Symposium, 2001; Yokota et al., 2008).

Weighted branch lines increase the sink rate of baited hooks, thereby reducing their accessibility to seabirds (Robertson et al., 2010, 2006). This is achieved by using branch lines with lead cores or adding lead weights near the hooks. The sink rate, which is typically measured at specific depths (e.g., 2, 5, and 10 m) and by the distance astern of the vessel to reach these depths, can help with evaluating the effectiveness of line weighting regimes (Anderson and Mcardle, 2002; Melvin et al., 2014). Appropriate benchmark depths are determined by factors such as the diving abilities of seabirds, the speed of a vessel during line setting, and the aerial coverage of BSLs.

Night setting is another highly effective mitigation measure for reducing seabird bycatch (Løkkeborg, 2008) because many seabird species are most active near dawn and dusk (BirdLife International Global Seabird Programme, 2009). Sánchez and Belda (2003) demonstrated in the area around the Columbretes Islands (northwestern Mediterranean) that Cory's shearwaters (*Calonectris diomedea*) are active at night, but despite this, bait loss from seabird attacks was approximately 80 % lower when setting lines at night than during sunrise or sunset. However, since the duration of daytime can be long in the high latitude in the summer, deploying a complete set at night can be challenging for fisheries operating at high latitude (Melvin et al., 2014). In some pelagic longline fisheries, due to the significant impact of operating times (day versus night) on the composition of catch species, there may be a reluctance to adopt seabird bycatch mitigation measures such as night setting (Orbesen et al., 2017). Thus, night setting is often rejected in favor of other mitigation measures. In addition, the effectiveness of night setting in reducing seabird bycatch, particularly albatross bycatch, decreases as moon illumination increases, necessitating the use of additional measures such as BSLs to achieve optimal outcomes (Jiménez et al., 2020).

Studies on the effects of different mitigation measures on target catch have reported diverse findings, highlighting the variations in fishing practices and target species behaviors (Avery et al., 2017; Robertson et al., 2013). Some studies have indicated that mitigation measures such as BSLs, night setting, and weighted branch lines can markedly reduce seabird bycatch without reducing target catch (Avery et al., 2017). However, other studies have suggested that although weighted hooks reduce seabird bycatch, they can alter fishing dynamics, necessitating adjustments in fishing techniques to avoid reductions in target catch (Sato et al., 2016; Yokota et al., 2008).

This study aims to identify the most effective mitigation measures for reducing seabird bycatch while minimizing impacts on target species catch in Taiwan's longline fishing fleet operating in the Atlantic Ocean. The Taiwanese longline fishery operates in the southeastern Atlantic Ocean and targets albacore (*Thunnus alalunga*). Previous observations have revealed that 28 seabird species are caught as bycatch by this fleet in the Atlantic, and the most frequently caught of these species are black-browed albatross (*Thalassarche melanophris*), yellow-nosed albatross (Atlantic) (*Thalassarche chlororhynchos*), wandering albatrosses (*Diomedea exulans*), spectacled petrel (*Procellaria conspicillata*), and southern giant petrel (*Macronectes giganteus*) (Yeh et al., 2013). Longline fishing in the study area is subject to regulations under the International Commission for the Conservation of Atlantic Tunas (ICCAT). ICCAT adopted Recommendation 11–09, which requires longline vessels located south of 25°S to implement at least two mitigation measures chosen from BSL, weighted branchline, and night setting. Although these recommendations are based on scientific evidence (Jiménez et al., 2020; Melvin et al., 2023; Rollinson et al., 2017), their effectiveness may vary across fleets and encountered species assemblage, necessitating performance evaluations for commercial longline fleets (Favero and Seco Pon, 2014; Melvin et al., 2019). Therefore, we conducted an experiment to assess the effectiveness of BSLs configured according to the conventional practices of Taiwanese skippers, comparing them to BSLs that meet ICCAT standards. Additionally, we examined whether the simultaneous use of BSLs with weighted branch lines,

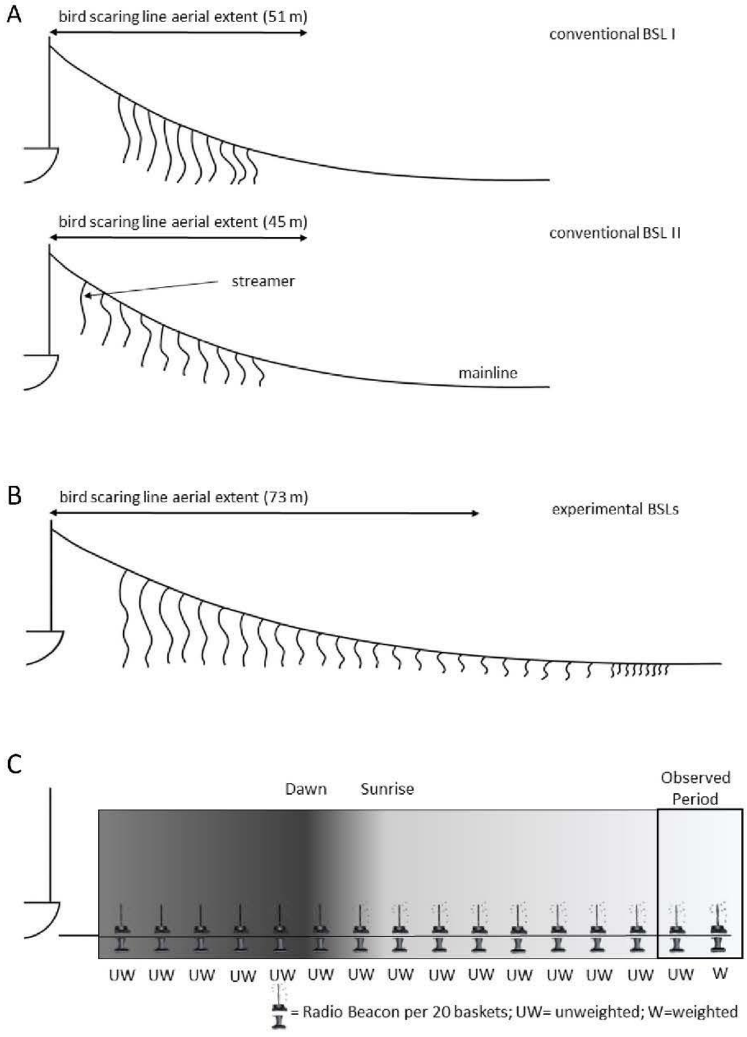

Fig. 1. A. Schematic diagrams of the conventional bird-scaring line (BSL) configuration, showing their respective aerial extents. B. Schematic diagram of the experimental BSL configuration, showing their respective aerial extent. C. Illustration of the experimental design comparing weighted and unweighted branchlines. In each set, the final segment consists exclusively of weighted branchlines, while all preceding segments use unweighted branchlines. The last two segments also correspond to the observation periods during which seabird abundance and attack behaviors were recorded. On average, approximately one-third of the sets were deployed at night.

or BSLs with night setting further improved seabird bycatch mitigation. It is important to note that the experimental BSLs used in this study did not meet ICCAT's minimum aerial extent requirement of 100 m for vessels over 35 m in length, nor did the night setting fully comply with ICCAT guidelines. This deviation reflects the operational constraints and prevailing practices of the Taiwanese longline fishery, allowing an assessment of mitigation performance under real-world conditions. In this study, we measured both seabird bycatch rates and albacore catch rates to evaluate the trade-offs between conservation and fishery efficiency. The results provide critical insights into optimizing seabird bycatch mitigation strategies for Taiwan's longline fleet while maintaining albacore catches in the Atlantic Ocean.

2. Methods

2.1. Longline vessel and gear

The experiment was conducted in 2013 aboard a commercial pelagic longline vessel targeting albacore tuna in the southeastern Atlantic Ocean. The vessel had a gross tonnage of 363 tons and a length of 42 m. Data were collected over 103 sets. Sardines (*Sardina pilchardus*) with an average weight of 86 g and an average length of 20 cm were used as bait. The conventional branch lines were 31 m long and did not have lead swivels, and each basket contained 12 conventional albacore hooks (3.2 sun). On average, 3800 hooks were used in each operation. The main line was set using a line shooter at a speed of 5.3 knots sinking to a target depth of 90–200 m. Bait was cast manually at a typical boat speed of 8.7 knots over the ground; the bait landed in a zone between the vessel and BSLs. Typically, one deployment was performed per day. Approximately 80 % of these operations began between 3 am and 6 am, with none starting later than 9 am, and around 80 % ended between 8 am and 1 pm. The average setting duration was approximately six hours, and the duration of 80 % of the operations ranged from 5.5 to 7 h.

2.2. Experimental design

2.2.1. BSLs

Four BSL-based mitigation measures (referred to as treatments) were evaluated in this study: a measure involving a single-conventional (SC) BSL, a measure involving double-conventional (DC) BSLs, a measure involving a single-experimental (SE) BSL, and a measure involving double-experimental (DE) BSLs. The conventional BSLs were designed by Taiwanese fishers, whereas the experimental BSLs were designed following the ICCAT Recommendations (ICCAT, 2011).

One conventional BSL was approximately 65 m long. It had streamers made of light blue polypropylene strips and yellow packing strap material. The streamers were 67–87 cm long and attached every 32 cm, with the exception of the first streamer that positioned closest to the stern (11 m away). The other conventional BSL was approximately 64 m long. It had streamers made of the same materials as those used in the aforementioned main line. The streamers were 72–87 cm long and attached every 73 cm, with the exception of the first streamer that positioned closest to the stern (6 m away). Both conventional BSLs were equipped with 10 streamers (Fig. 1A). The crew arbitrarily selected one of the two BSLs for SC treatment to mimic real-world conditions.

The experimental BSLs were 125 m long. These lines had streamers made of blue and red polypropylene strings and yellow packing strap material arranged arbitrarily. The first streamer was positioned closest to the stern (10 m away). The subsequent streamers were 1.5–10 m long and attached every 2.5 m for the first 100 m of the main line. Beyond this distance, the streamers were 1 m long and attached every 0.5 m (Fig. 1B). The BSLs were attached to tori poles on the upper deck, positioned to the port and starboard sides of the stern.

A set was treated as an experimental unit. Considering feasibility constraints on a commercial vessel, we adopted a systematic design instead of randomization. To ensure a balanced distribution of data across treatments, the trip duration (days) was divided into specific sequences. For the first 20 days, the treatments were assigned in the following order: SC, DC, SE, and DE. In the subsequent days, the treatments were applied in a reverse order: DE, SE, DC, and SC. In total, 103 sets were conducted.

2.2.2. Weighted branch lines

Each set was stratified into several segments by radar beacons; each segment comprised 20 baskets, with a total of 240 hooks. To avoid interference in commercial fishing operations, a 60-g lead swivel was attached 3 m above the hook on branchlines in the last (20th) basket of each set. A total of 240 lines per set were deployed with line weights (6.25 % of all hooks set). Our focus was on the sink rate of baited hooks (Fig. 1C).

To estimate the sink rate of baited hooks for each set, four time–depth recorders (TDRs) were attached to the shallowest (closest to the floats) and deepest (furthest from the floats) hooks of two adjacent baskets in both unweighted and weighted branch lines. The TDRs were positioned 0.3 m above the hooks. The sink rate of baited hooks was assumed to be independent of other hooks (Anderson and Mcardle, 2002). On the basis of the depth of the baited hooks and the presence of a 60-g swivel weight, we formed four experimental configurations: shallow without weight, shallow with weight, deep without weight, and deep with weight.

2.3. Data collection

Data pertaining to the physical environment and vessel operations were collected during line setting. The collected data included the latitude and longitude at the setting location, maximum visibility, moon phase, sea surface temperature, set duration, BSL's aerial coverage, swell height, total hook count, vessel speed, and wind speed (Beaufort Sea state) and direction.

Trained observers recorded the numbers of seabird attacks on baited hooks and seabird sightings during the daylight hours of each set during both the setting and hauling processes. The observers recorded primary and secondary attacks during the setting and hauling of the last gear segment of unweighted branch lines and the gear segment of weighted branch lines; each observation lasted approximately 15–20 min per segment. Therefore, a total of 49,440 hooks were observed during line setting operations, based on 40 baskets sampled per set across 103 sets.

A primary attack was considered to be an individual bird attempting to take bait from a hook, typically by making a dive, lunge, or plunge directly over a sinking hook. A secondary attack was considered to be a case in which another bird or a group of birds attempted to steal bait from a bird that had successfully taken it to the surface after a primary attack. A foraging guild was defined as the primary foraging strategy used by a species. Wilman et al. (2014) quantified the foraging strategies of various species by assigning scores ranging from 0 % to 100 % for each guild, with these scores reflecting the relative usage of specific strategies. On the basis of these scores, this study categorized the seabirds into divers and surface feeders. Each seabird species was classified into either guild in accordance with its predominant foraging strategy, determined by a score of $\geq$ 50 %.

During line setting, both diving and surface foraging attacks were recorded in 1 of 21 locations delineated by 7 longitudinal areas (0–25, 26–50, 51–75, 76–100, 101–125, 126–150, and 151–200 m astern) and 3 lateral areas (within the 2 BSLs, port side of the port line, or starboard side of the BSL). Markers were inserted into the BSLs to establish reference points for estimating distance astern. In addition, gear floats were used as reference points; floats were positioned between the baskets, and the distance between two consecutive floats was approximately 330 m. This distance was estimated by calculating the total distance between the coordinates at the start of the first hook and the end of the last hook, divided by the total number of baskets. Observers visually recorded the longitudinal areas using these two reference points. Seabirds sighted (in the air and on water) within a 250-m hemisphere centered at the stern midpoint were counted and stratified by species before the estimation of attack rates.

During hauling, one observer recorded fish catches by species over two 4-hours observation periods as well as the order and specifications of the hooks that caught the fish. Another observer recorded seabird bycatch by species during the retrieval of all hooks as well as the order and specifications of the hooks that caught the seabirds.

Based on these records and the assumption that the setting operation was conducted at a constant speed, this allowed us to distinguish whether specific baskets were deployed during daylight or nighttime operations. During hauling operations, observers recorded the basket number where fish and seabird bycatch events occurred. By integrating these records, we retrospectively determined whether caught fish and bycaught seabirds were captured by the night or daylight setting operations.

The Star-Oddi DST Centi–TD loggers were used as TDRs, measuring depth with $\pm$0.4 % accuracy. Data were recorded at 1-s intervals while hooks were in the water. Depth and time were sampled at 0.5-m and 1-s intervals, respectively.

2.4. Statistical analysis

Given the availability of species-specific data and the assumption that adjacent segments within each set were subject to similar environmental and operational conditions, paired t-tests were conducted to compare the rates of primary and secondary seabird attacks between unweighted and weighted branchlines during line setting. The use of adjacent segments as matched pairs served as a control to minimize variability unrelated to the treatment. Sink profiles with unweighted and weighted branch lines were derived using TDRs to estimate how far astern baited hooks reached specific depths. A two-way ANOVA was performed to compare mean sink times at three depths (2, 5, and 10 m) between unweighted and weighted branch lines.

The relationships between seabird bycatch rate (number per 1000 hooks) and 13 explanatory variables—latitude, longitude, vessel speed, weather, wind speed, wind direction, wave height, depth, temperature, BSL type, branchline weighting, month, and night setting ratio (NightSR)—were examined using a generalized linear model (GLM). The NightSR was defined as the proportion of hooks deployed at night within a given set, where NightSR = 0 indicates a fully daylight set and NightSR = 1 indicates a fully night set.

Bycatch rates for weighted and unweighted branchlines were calculated separately for each set. Night setting was defined as any setting activity occurring between the end of nautical twilight in the evening and before nautical dawn in the morning. Since commercial albacore vessels typically did not conduct full night sets, NightSR was used as a proxy to assess the influence of partial night setting on seabird bycatch. A negative binomial distribution was applied to the model to account for potential overdispersion in the bycatch data.

Generalized linear mixed models were used to investigate the effects of various mitigation measures on albacore catch rates. The fixed factors included latitude, longitude, day–night (if albacore was caught by daytime or nighttime setting hooks), branch line weighting, soak time, and BSL type. Albacore catch rates with weighted and unweighted hooks, by daytime or nighttime setting hooks, were calculated separately. In a typical set operation, the gear was deployed in multiple segments, usually 16 or 17. We defined soak time as the average operational duration of a single segment, measured in relation to the order of immersion. Specifically, soak time was calculated in reverse order of deployment, using the last segment as the reference point. The soak time of each segment represented the number of unit times that a segment remained submerged compared to the last segment. For example, in a set operation with 16 segments, fish catch records were obtained during the hauling operation using two observation shifts, each lasting four hours. During these shifts, we recorded catch data for segments 7, 8, 14, 15, and 16, with segment 16 being the last deployed. The corresponding soak times for these segments were 9, 8, 2, 1, and 0, respectively. Considering that the duration each segment remained in the water might affect the target catch, we incorporated soak time as a variable in the GLMM model to account for its potential impact. Fishing set and gear segments were regarded as random effects to account for overdispersion (Breslow, 1990).

3. Results

3.1. Trip information

Fishing sets were conducted from April 27 to August 17, 2013. Initially, vessels operated around 35°S and 15°E; however, because of severe weather in early June, they moved northward to approximately 30°S and then continued westward to approximately 5°W. The overall distribution of the fishing sets extended from approximately 35°S, 10°W to 35°S, 15°E (Fig. 2). A total of 103 fishing sets were conducted. The SC, DC, SE, and DE treatments were applied for 24, 22, 29, and 28 sets, respectively. A total of 48,382 hooks were observed to record seabird sightings and attack behaviors across the different treatments. During the study period, BSLs broke twice, and streamers tangled with BSLs five times; these instances were excluded from relevant analyses. Fig. 2 depicts the locations of the sets corresponding to different BSL treatments.

During the study period, the wind speed ranged from 0.6–3 knots (light air) to 21–26.9 knots (strong breeze). The wave height ranged from 0 to 4 m. The fishing sets typically began between 3 and 6 AM and lasted 6–6.5 h; after 0.5–1 h, hauling began. Setting 20 baskets required approximately 20 min, whereas hauling them required approximately 1 h. For most sets, the last 40 baskets remained in the water for 2 h, whereas some remained for 4 h. Two sets lasted for up to 17 h.

3.2. Seabird interactions

We observed 22 species of seabirds during setting and hauling (Table 2 and Table A1). The most frequently observed seabird species during the study were White-chinned Petrel and Great Shearwater. The most frequently observed seabird species—recorded on > 70 % of all sets—were the white-chinned petrel, spectacled petrel, cape petrel (*Daption capense*), black-browed albatross, and yellow-nosed albatross (Atlantic) (Fig. 3). Among the divers, the most abundant species were the white-chinned petrel, spectacled petrel, and great shearwater; on average, approximately 30 great shearwaters were noted per observation in regions located south of 35°S. Among the surface feeders, the most abundant species were the black-browed albatross and cape petrel. Our observations align with the

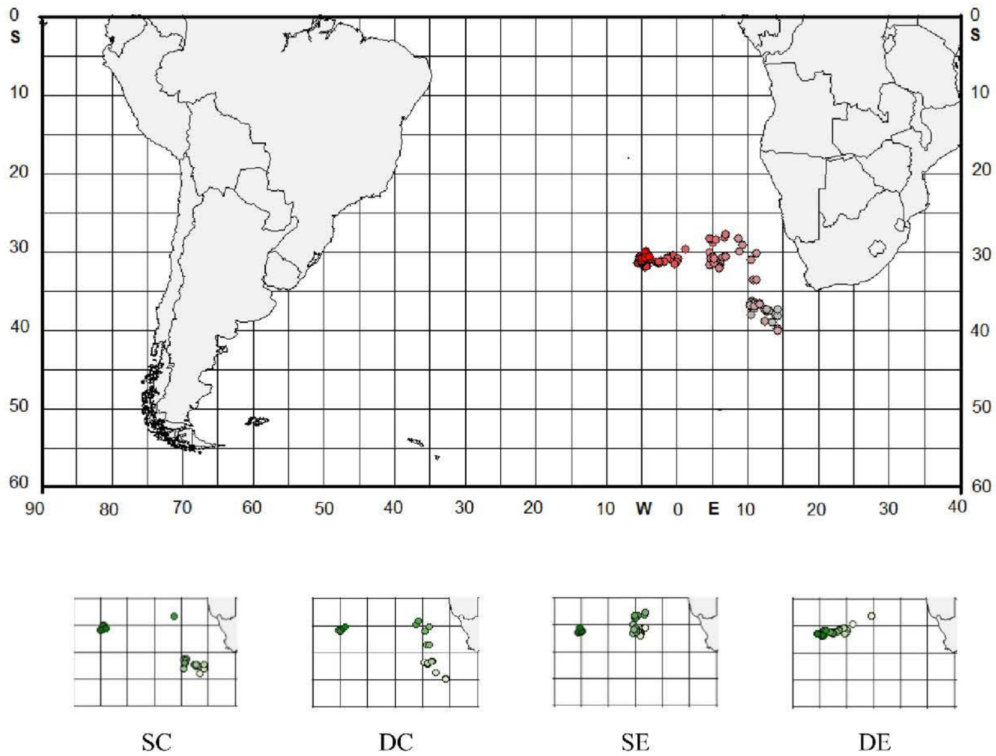

Fig. 2. Map of the study area and experimental design distributions. The color gradients indicate the experimental timeline, with light red and green representing the early stages and dark red and green indicating later stages. The four lower panels show the spatial distributions of different experimental configurations: SC, DC, SE, and DE.

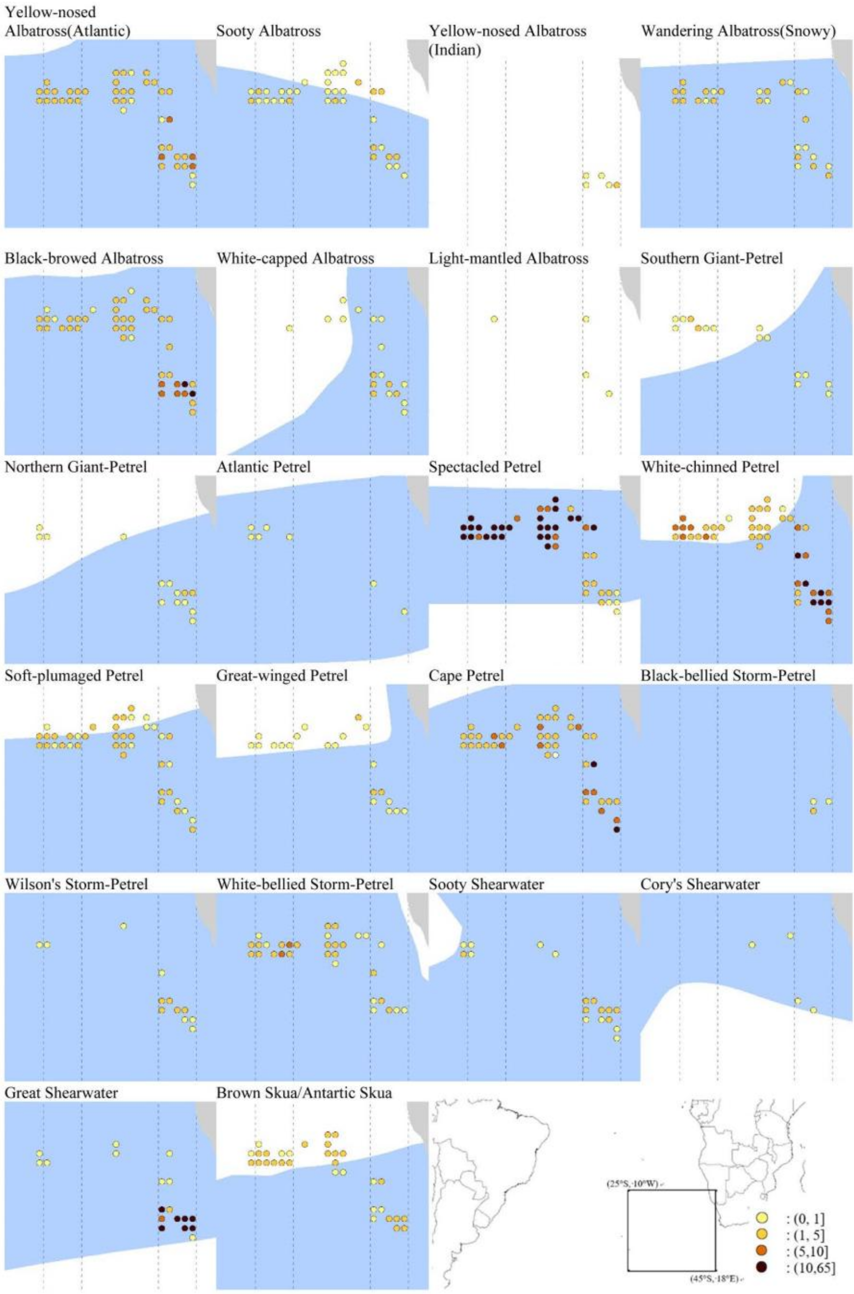

Fig. 3. Sighting locations and observed abundance of 22 seabird species during the experiment. Blue shading represents the species' distribution in the study area, as defined by the International Union for Conservation of Nature (IUCN) Red List of Threatened Species. Colored points indicate the mean number of birds observed per observation. The right-bottom panel outlines the spatial extent of the study area covered by the other panels. The legend represents categories of birds observed per session: (0,1], (1,5], (5,10], and (10,65].

distributions reported by the International Union for Conservation of Nature (IUCN) for most species, except for the yellow-nosed albatross (Indian) (*Thalassarche chlororhynchos bassi*) and light-mantled albatross (*Phoebetria palpebrata*). The distribution map does not extend the yellow-nosed albatross (Indian) into the Atlantic Ocean, and the light-mantled albatross is typically found south of 45°S. Overall, the rate of seabird attacks on baited hooks was 2.2 times higher with unweighted branch lines than with weighted branch lines. The rates of primary and secondary attacks were the highest for great shearwaters (divers) and black-browed albatrosses (surface feeders), respectively. Primary attacks were made by sooty albatrosses (*Phoebetria fusca*), sooty shearwaters (*Puffinus griseus*), and southern giant-petrels (*Macronectes giganteus*) on unweighted branch lines but not on weighted branch lines. The numbers of attacks during hauling were similar between the unweighted and weighted branch lines (Table A1).

Data on seabird attacks from the center, port, and starboard sides of the vessel were combined to enable comparison of the distribution of attacks between divers and surface feeders. Overall, the rates of attacks—both primary attacks by divers and secondary attacks by surface feeders—on baited hooks were higher with unweighted branch lines, regardless of BSL type, than with weighted branch lines (Fig. 4). Primary attacks were made mostly by divers, whereas secondary attacks were made mostly by surface feeders.

3.3. *Sink rate of baited hooks*

A total of 194 TDR records were collected for the four configurations. The shallowest and deepest hooks in the fishing gear deployments were typically at depths near 100 or 200 m. No crew members were injured during the study, indicating that the

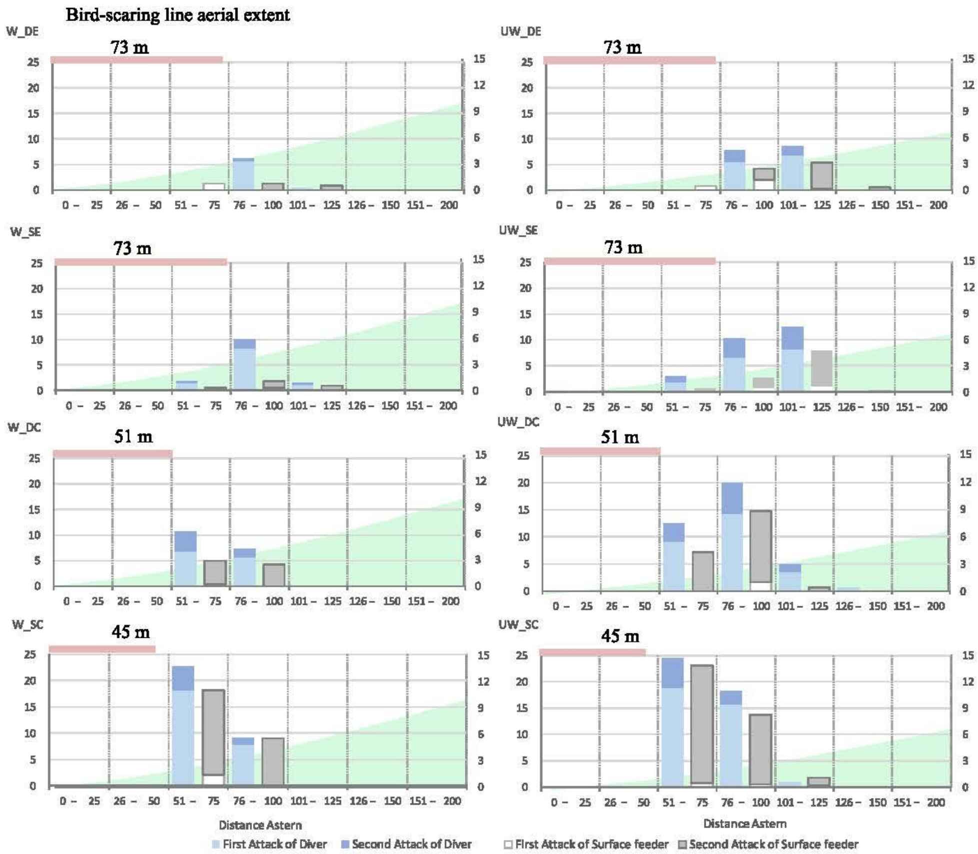

Fig. 4. Seabird attack rates (attacks per 1000 hooks) by diving and surface-foraging seabirds under different branch line and bird-scaring line configurations. The left column of panels represents weighted branch lines, while the right column represents unweighted branch lines. From top to bottom, the four rows correspond to different bird-scaring line configurations: DE, SE, DC, and SC. Light blue bars indicate primary attacks by diving seabirds, while dark blue bars represent secondary attacks by diving seabirds. Similarly, white bars show primary attacks by surface-foraging seabirds, and gray bars indicate secondary attacks by surface-foraging seabirds. The green shaded area represents the depth of baited hooks relative to the astern distance from the vessel. The right y-axis shows the sinking depth of baited hooks, while the left y-axis represents the number of seabird attacks. The orange bar denotes the aerial extent of the bird-scaring line.

experimental weighted branch lines were safe for use.

The influence of gear configuration on sink rates was considered in relation to the structural arrangement of the longline system. Each basket contained 12 hooks, with buoys positioned at both ends. This setup resulted in a catenary-shaped suspension of the mainline between floats, causing hooks at different positions to reach varying depths after deployment. Given this configuration, we aimed to evaluate whether shallow and deep hooks exhibited different sink rates at various depths, based on their relative positions within the gear structure. For the weighted branch lines, baited hooks sank to a depth of 5 m (sink rate is 0.18 m/s) within 100 m astern of the vessel. When the aerial coverage was short (~50 m), that is, for the DC and SC treatments cases, seabird attacks occurred within 51–100 m astern. In the DE and SE treatments, where the aerial extent of the streamer line was longer (~73 m), the baited hook reached a depth of approximately 3 m (sink rate ≈ 0.13 m/s) at the terminus of the streamer line. Seabird attacks were concentrated within 76–100 m astern and extended beyond 125 m. For the unweighted branch lines, baited hooks sank to a depth of 5 m (sink rate is 0.13 m/s) within 100 m astern of the vessel. When the aerial coverage was short (~50 m), seabird attacks were occurred within 51–125 m astern. When the aerial coverage was longer (~73 m), the baited hook reached a depth of approximately 3 m (sink rate ≈ 0.10 m/s) at the terminus of the streamer line. Seabird attacks concentrated within 76–125 m astern, and extended beyond to 150 m.

The difference in sink rate caused the baited hooks on the weighted branch lines to reach their given depth at a distance closer to the vessel than the hooks on the unweighted branch lines. Both types of branch lines sank to a depth of 10 m, well beyond the aerial coverage of the BSLs. For the unweighted branch lines, the hooks reached a depth of 6 m at around 200 m from the vessel. By contrast, for the weighted branch lines, the hooks reached a depth of 9 m at the same distance (Fig. 4). ANOVA revealed that the time required for sinking hooks to depths of 2, 5, and 10 m did not differ significantly between the shallow and deep hooks. When the data for the shallow and deep hooks in the baskets were combined, the weighted branch lines were determined to sink considerably faster than the unweighted branch lines did to all benchmark depths (Fig. 5). During the initial stage of sinking, that is, within the first 10 m, the weighted hooks sank faster than the unweighted hooks did. At deeper depths, the sink rate was influenced by the entire gear configuration, including the main line and assembled hooks. At depths of 2, 5, and 10 m, the sink rates of the baited hooks were 31.3 %, 26.7 %, and 25.3 % faster, with the weighted branch lines than with the unweighted branch lines.

3.4. Seabird bycatch

During the observation period in which seabird abundance and attack behaviors were recorded, 46 seabirds were caught on the corresponding unweighted branch lines and 18 on the corresponding weighted branch lines. These bycatch numbers align with the observed attack rates and are summarized by species in Table 2, allowing for a direct comparison among species-specific abundance, attack behavior, and bycatch incidence. Although attacks by white-capped albatrosses (*Thalassarche cauta*), cape petrels, and brown skuas were observed, no bycatch was recorded for these species. A total of 316 seabirds were recorded as bycaught from 103 fishing sets, based on data collected during the retrieval of all hooks. Of these, 298 seabirds were caught during setting operations and recovered dead, 4 were caught alive during hauling, and 14 were caught alive by trolling lines. This resulted in a total observed bycatch rate of 0.75 birds per 1000 hooks (Table 1). Specifically, for daytime setting operations with BSLs and unweighted branchlines, a total of 292 274 seabirds were caught, corresponding to a catch rate of 1.2 birds per 1000 hooks. For 293 nighttime setting operations with

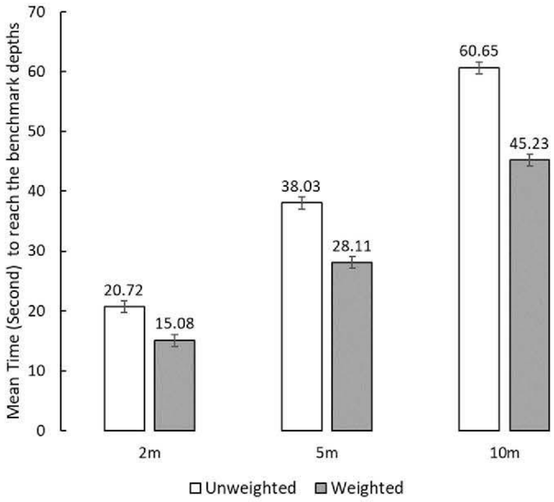

Fig. 5. Mean sinking time of baited hooks to reach 2 m, 5 m, and 10 m benchmark depths with unweighted and weighted branch lines. Sinking time is measured in seconds. Statistical comparisons were conducted using Two-way ANOVA (depth × branchline type). Error bars represent 95 % confidence intervals.

BSLs and unweighted branchlines, 6 seabirds were caught, with a catch rate of 0.04 birds per 1000 hooks. Additionally, for daytime settings with weighted branchlines, 18 seabirds were caught, resulting in a catch rate of 0.75 birds per 1000 hooks. No weighted branchlines were deployed during nighttime settings. The seabird species caught during hauling included the great shearwater (*Puffinus gravis*), black-browed albatross, and spectacled petrel. Besides, trolling lines were used by the crew during the haul as a recreational activity, separate from the main fishery operation. Seabirds caught by trolling lines were released alive. Fig. 6 presents the bycatch rates for six species, which accounted for > 98 % of all seabird mortalities. Black-browed albatrosses exhibited the highest bycatch rate (2.90 birds/1000 hooks) in the SC treatment with unweighted branch lines. For all BSL types, the bycatch rates for the six seabird species were lower with weighted branch lines than with unweighted branch lines. The rates of seabird bycatch for all species, except for white-chinned petrels and spectacled petrels, were the lowest for the DE treatment, followed by the SE, DC, and SC treatments.

GLMs were used to identify the correlations of seabird bycatch with 13 variables, such as latitude, wave height, and temperature. Seven GLMs were constructed: one for each of the six species and one for all species combined (Tables A2–A8). Initially, a univariate GLM was constructed for the number of seabird bycatch. Significant variables ($p < 0.05$) from the univariate model were used to develop a multivariate GLM. The analysis results for all species combined (Table A2) indicated that seabird bycatch was significantly, negatively correlated with both weighted branch lines and temperature ($p < 0.001$ and $p = 0.0046$, respectively). The number of seabird bycatch was significantly lower in May than in April ($p = 0.013$); however, the other months exhibited no significant differences. Notably, NightSR and BSL type exerted no significant effect on bycatch rate. In the seabird bycatch analysis, although the GLM model included only 13 variables, some of these variables contained multiple categories, resulting in a total of 29 actual variables. For each species, we had 202 observed data points, yielding a variable-to-sample ratio of approximately 1:7. While this is slightly below the commonly suggested ratio of 1:10, it is still considered acceptable for model estimation.

Table 3 presents the significant variables across the seven GLM models. The results confirmed the significant, negative correlations of seabird bycatch with weighted branch lines and temperature. For sooty albatrosses, an inverse correlation was noted between bycatch rate and wave height; larger waves were significantly associated with lower bycatch rates.

On average, approximately 35 % of all hooks were set at night for each set. A total of 296 bycatch instances occurred during daytime, whereas only 6 occurred at night. All birds caught at night were white-chinned petrels; three of these were caught on nights bracketing the full moon. Overall speaking, the seabird bycatch rate was 23.83 times higher during daytime (1.101 birds/1000 hooks) than nighttime (0.046 birds/1000 hooks). The bycatch rate for white-chinned petrels was 5.8 times higher during daytime (0.29 birds/1000 hooks) than during nighttime (0.05 birds/1000 hooks).

Table 1
Summary statistics of metrics to evaluate the effect of unweighted and weighted branch lines and nighttime vs. daytime setting on seabirds and target fishes.

Metric	Whole trip	
Total hooks in the trip	394,972 hooks	
Birds caught	316	
During Setting	298	
During hauling	4	
By trolling	14	
	Unweighted branch lines	**Weighted branch lines**
Total Hooks	370,962	24,010
Bird caught		
During Day	274	18
During Night	6	N/A
Albacore caught	9399	391
Bird bycatch rate (bird/1000 hooks)		
By daytime setting	1.20	0.75
By nighttime setting	0.04	N/A
Albacore catch rate (no./1000 hooks)	25.34	16.28
By daytime setting	30.41	18.22
By nighttime setting	28.79	N/A
Number of hooks observed in setting	**24,372**	**24,010**
Primary attacks times	365	184
Diver birds	336	169
Surface feeder	29	15
Secondary attacks	401	162
Diver birds	110	41
Surface feeder	291	121
Attack rate (attack/1000 hooks)	31.4	14.4
Sink rate (m/s to 10 m)	0.24	0.3
Astern distance to 10 m depth (m)	273	206

Note: N/A not applicable.

Table 2
Mean seabird sighting and standard error (SE), sets present, attack rates and numbers of seabird bycatch during observed period during the set with unweighted and weighted branch lines, stratified by species and foraging guild. The bold and significance levels relate to and W and UW are pooled across BSL designs and numbers.

Guild	Common name (Scientific name)	IUCN Status	Sighting during UW					Sighting during W				
Diver bird			Sightings (SE)	1st Attack per 1000 hooks	2nd Attack per 1000 hooks	Attend sets	No. of bycatch	Sightings (SE)	1st Attack per 1000 hooks	2nd Attack per 1000 hooks	Attend sets	No. of bycatch
	White-chinned Petrel (Procellaria aequinoctialis)	VU	5.27(0.54)	**3.53 (0.78)**	1.39(0.37)	99	13	5.02(0.52)	**2.01(0.45)***	0.90(0.34)	99	3
	Spectacled Petrel (Procellaria conspicillata)	VU	10.71 (0.79)	**6.95(1.05)**	**3.06(0.68)**	92	3	9.55(0.69)	**2.56(0.47)*****	**0.57(0.21)*****	95	
	Great Shearwater (*Puffinus gravis*)	LC	16.39 (2.94)	**35.48(6.19)**	7.71(2.66)	28	9	17.70 (3.82)	**17.57(3.38)****	3.39(1.84)	27	7
	Sooty Shearwater (*Puffinus griseus*)	NT	1.64(0.75)	0.79(0.79)		14		1.71(0.27)			15	1
	Cory's Shearwater (*Calonectris diomedea*)	LC	1.00(0.00)			1		1.00(0.00)			1	
Surface feeder												
	Cape Petrel (Daption capense)	LC	3.57(0.28)			84		3.75(0.29)	0.13(0.09)		85	
	Yellow-nosed Albatross, Atlantic (*Thalassarche chlororhynchos chlororhynchos*)	EN	3.24(0.33)		**9.40(1.80)**	77	7	2.94(0.28)	0.07(0.07)	**2.94(0.76)*****	78	
	Black-browed Albatross (*Thalassarche melanophris melanophris*)	LC	3.38(0.38)	1.37(0.41)	**11.16(1.93)**	74	11	3.27(0.50)	0.62(0.31)	**5.14(1.17)*****	78	7
	Soft-plumaged Petrel (*Pterodroma mollis*)	LC	1.20(0.07)			61		1.28(0.07)			53	
	White-bellied Storm-Petrel (*Fregetta grallaria*)	LC	3.43(0.47)			42		3.56(0.50)			41	
	Brown Skua/Antartic Skua (*Catharacta antarctica*)	LC	1.51(0.13)	0.71(0.28)	**1.38(0.59)**	41		1.62(0.16)	0.43(0.24)	**0.16(0.16)***	39	
	Sooty Albatross (*Phoebetria fusca*)	EN	1.18(0.07)	0.40(0.40)	0.82(0.49)	28	2	1.26(0.09)		0.14(0.14)	39	
	Wandering Albatross, Snowy (*Diomedea exulans exulans*)	VU	1.17(0.08)		1.13(0.57)	24		1.18(0.09)		0.20(0.19)	28	
	Southern Giant-Petrel (*Macronectes giganteus*)	LC	1.17(0.11)	0.43(0.43)	1.30(0.68)	12		1.09(0.09)		1.01(0.65)	11	
	Wilson's Storm-Petrel (*Oceanites oceanicus*)	LC	2.44(0.88)			9		2.25(0.51)			12	
	Great-winged Petrel (*Pterodroma macroptera*)	LC	1.22(0.15)			9		1.13(0.13)			8	
	Northern Giant-Petrel (*Macronectes halli*)	LC	1.00(0.00)		0.74(0.80)	6	1	1.33(0.33)			3	
	White-capped Albatross (*Thalassarche cauta*)	NT	1.50(0.50)		3.82(2.62)	4		1.20(0.20)		1.11(1.01)	5	
	Atlantic Petrel (*Pterodroma incerta*)	EN	1.00(0.22)			3		1.00(0.00)			3	
	Yellow-nosed Albatross, Indian (*Thalassarche chlororhynchos bassi*)	EN	1.00(0.00)			2		1.00(0.00)			2	
	Light-mantled Albatross (*Phoebetria palpebrata*)	NT	1.00(0.00)			1		1.00(0.00)			2	
	Black-bellied Storm-Petrel (*Fregetta tropica*)	LC	1.00(0.00)			1		2.00(0.00)			1	

Note: Status is shown by IUCN criteria, where LC: Least Concern, NT: Near Threatened, VU: Vulnerable, EN: Endangered, see details inwww.birdlife.org/datazone/speies/search https://iucn.org/resources/publication/iucn-red-list-categories-and-criteria-version-31 (IUCN, 2001). *:$P < 0.05$, **:$P < 0.01$, ***:$P < 0.001$

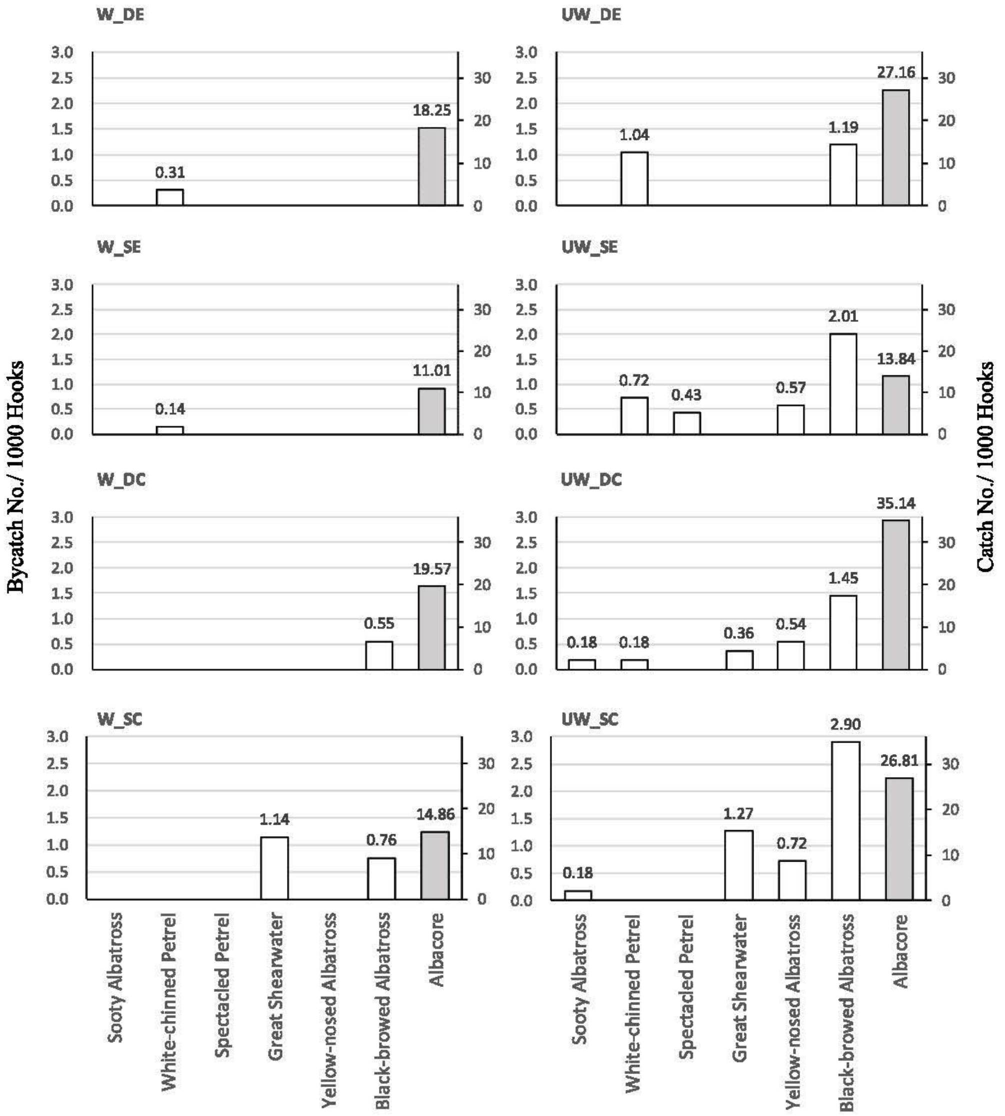

Fig. 6. Bycatch rates for six seabird species and albacore catch rate under different branch line and bird-scaring line configurations. The left column of panels represents weighted branch lines, while the right column represents unweighted branch lines. From top to bottom, the four rows correspond to different bird-scaring line configurations: DE, SE, DC, and SC. This graph illustrates the bycatch rates for six seabird species alongside the albacore catch rate, under different branch line and bird-scaring line configurations. The left y-axis denotes seabird bycatch rates, while the right y-axis indicates the albacore catch rate, providing an overview of the effect on both seabirds and the target species.

3.5. Albacore catch rate

During the retrieval process, our observers worked in two shifts per day, each lasting four hours. During these shifts, they recorded the specific basket in which the albacore catch occurred, allowing us to determine whether the catch was made using a weighted or unweighted branch line. Fig. 6 compare the fish catch rates across the different treatments. The mean catch rate of albacore was determined to be 11.01–35.14 fish per 1000 hooks for all treatments.

In the initial GLMM model, we considered six main variables: latitude, longitude, weight, soak time, BSL type, and setting time (day/night), along with all pairwise interaction terms and two random variables. The results indicated that the interaction between

Table 3
Significant variables identified by the generalized linear model for total seabird and each species.

	Total	Great Shearwater	Spectacled Petrel	Sooty Albatross	Yellow-nosed Albatross (Atlantic)	White-chinned Petrel	Black-browed Albatross
Lat			0.341*				
Lon		0.800**					
Wave							
Small swell				−4.587***			
Moderate swell				−4.339***			
Temperature	−0.432**	−0.574**			−1.091*		
Branch lines	−2.762***	−2.165***				−3.309***	−2.139***
Month	−2.032*						
NightSR			3.642**				

Note: *:P < 0.05, **:P < 0.01, ***:P < 0.001

setting time and soak time, as well as the interaction between BSL type and soak time, were statistically significant. This finding suggests that the effects of the variables vary under different settings, highlighting the need for subgroup analyses. The results of the subgroup analysis by setting time are summarized in Table 4. The day group contained 618 observations, including 527 unweighted and 91 weighted branch lines. fish catch rates showed a statistically significant increasing trend toward the north and west (Table 4a).

Table 4
Table of fixed effects from the generalized linear mixed model (GLMM) fitted to albacore catch rates per segment, based on data collected during 103 hauling operations by two observation shifts, each lasting four hours.

(a) GLMM analysis results for albacore catch rates in the daytime setting subgroup.

Variable	coefficient (95 % CI)	*P* value
Intercept	−0.079 (−1.128, 0.970)	0.882
Latitude	−0.097 (−0.130, −0.064)	< 0.001
Longitude	−0.043 (−0.058, −0.029)	< 0.001
Weight	−0.321 (−0.514, −0.128)	0.001
Soak time	0.068 (0.046, 0.091)	< 0.001
BSL		
DE	reference	
DC	0.168 (−0.052, 0.388)	0.134
SE	−0.122 (−0.316, 0.072)	0.219
SC	−0.132 (−0.369, 0.106)	0.277

(b) GLMM analysis results for albacore catch rate in the nighttime setting subgroup

Variable	coefficient (95 % CI)	*P* value
Intercept	0.182 (−2.376, 2.740)	0.889
Latitude	−0.102 (−0.184, −0.021)	0.014
Longitude	−0.056 (−0.094, −0.018)	0.004
Soak time	−0.041 (−0.109, 0.027)	0.241
BSL		
DE	reference	
DC	0.233 (−0.689, 1.154)	0.621
SE	0.339 (−0.083, 0.761)	0.115
SC	0.389 (−0.154, 0.931)	0.160

(c) GLMM analysis results for albacore catch rate by BSL types

	DE (n = 196)		**DC** (n = 144)	
Variable	coefficient (95 % CI)	*P* value	coefficient (95 % CI)	*P* value
Intercept	−4.841 (−11.430, 1.749)	0.150	1.371 (−0.134, 2.876)	0.074
Latitude	−0.255 (−0.472, −0.039)	0.021	−0.058 (−0.105, −0.011)	0.016
Longitude	−0.007 (−0.083, 0.069)	0.861	−0.033 (−0.056, −0.010)	0.004
DayNight	−0.474 (−0.838, −0.110)	0.011	−0.558 (−1.342, 0.227)	0.163
Weight	−0.279 (−0.640, 0.082)	0.129	−0.291 (−0.674, 0.093)	0.137
Soak time	0.049 (0.010, 0.088)	0.013	0.057 (0.014, 0.100)	0.009
	SE (n = 234)		**SC** (n = 165)	
Variable	coefficient (95 % CI)	*P* value	coefficient (95 % CI)	*P* value
Intercept	1.127 (−1.538, 3.793)	0.407	−2.845 (−6.077, 0.386)	0.084
Latitude	−0.055 (−0.142, 0.032)	0.213	−0.181 (−0.282, −0.080)	< 0.001
Longitude	−0.050 (−0.074, −0.026)	< 0.001	−0.075 (−0.123, −0.028)	0.002
DayNight	−0.051 (−0.361, 0.258)	0.746	−0.008 (−0.409, 0.394)	0.971
Weight	−0.414 (−0.805, −0.023)	0.038	−0.508 (−0.893, −0.122)	0.010
Soak time	0.059 (0.019, 0.099)	0.004	0.058 (0.010, 0.106)	0.019

During daytime, fish catch rate was 32.1 % lower with weighted branch lines than with unweighted branch lines ($p = 0.001$). Furthermore, for one unit increase in soak time, fish catch rate increased by 6.8 % ($p < 0.001$). Regarding BSL type, the results indicated no significant difference in albacore catch rate.

The night group contained 121 observations, all of which were unweighted. Because the night data did not include outcomes pertaining to weighted branch lines, the analysis for this subset focused on latitude, longitude, soak time and BSL type. Except for the soak time variable, the relationships between albacore catch rates and the explanatory variables closely resembled those in the daytime group. Regarding soak time, the result indicated no significant difference in fish catch rate (Table 4b).

The results of the subgroup analysis by BSL type are summarized in Table 4c. For the subgroup analysis by BSL type, the number of observations for each type was as follows: DE (196), DC (144), SE (234), and SC (165). Soak time significantly influenced the outcomes of all BSL treatments (DE: $p = 0.013$, DC: $p = 0.009$, SE: $p < 0.004$, and SC: $p = 0.019$). However, setting time (day/night) significantly influenced the outcomes of only the DE treatment ($p = 0.011$), whereas weight significantly influenced the outcomes of only the SE and SC treatments (SE: $p = 0.038$ and SC: $p = 0.010$). For the fish catch rate analysis, the variable-to-sample ratio in all subgroups was far greater than 1:10, indicating that there was no concern about having too few samples or too many variables.

4. Discussion

4.1. Seabird sighting and bycatch

Observation of seabirds attending fishing vessels provides valuable insights into seabird distribution and helps with determining the overlap between fisheries and seabird habitats. Between 2002 and 2016, 28 seabird species were documented across pelagic longline fleets in the South Atlantic Ocean and southwestern Indian Ocean (Jiménez et al., 2020). We observed 60 % of these species and recorded six additional species, namely, Wilson's storm-petrel (*Oceanites oceanicus*), white-capped albatross, white-bellied storm-petrel, black-bellied storm-petrel, Atlantic petrel (*Pterodroma incerta*), and soft-plumaged petrel (*Pterodroma mollis*). Notably, the Atlantic petrel is classified as an endangered species; this indicates that the fisheries operations in these regions pose potential conservation risks, despite no attack behavior being observed in the present study.

Between 2018 and 2020, albatrosses constituted 70 % of all seabirds caught as bycatch in the Pacific Ocean albacore longline fishery (Gilman et al., 2023). In the Uruguayan pelagic longline fleet in the southwest Atlantic Ocean, albatrosses constituted > 90 % of all seabirds caught as bycatch (n = 598) (Jimenez et al., 2010). In contrast, albatrosses comprised only 35 % of the seabird bycatch in the albacore longline fishery (operating in the southeastern Atlantic Ocean) assessed in our study. However, these figures may not be directly comparable due to differences in several factors, including the implementation of mitigation measures, the number of vessels sampled, and the temporal coverage of the data. Data corresponding to the period of 2001–2014 indicated that the seabird bycatch in the pelagic longline fleet in the Atlantic Ocean predominantly comprised Atlantic black-browed albatrosses, great shearwaters, and white-chinned petrels (Jimenez et al., 2010; Seco Pon et al., 2007; Tamini et al., 2015; Tuck et al., 2011). A similar trend was observed in our study; the bycatch primarily comprised white-chinned petrels, great shearwaters, black-browed albatrosses, spectacled petrels, yellow-nosed albatrosses (Atlantic), and sooty albatrosses.

White-chinned and spectacled petrels are prevalent in the Southern Ocean. Because of their cathemeral activity and aggressive feeding behavior, these seabirds face major threats from longline fisheries. The rate of bycatch is the highest for white-chinned petrels because they are particularly difficult to deter from baited hooks and highly susceptible to incidental capture (Phillips et al., 2006; Ryan et al., 2012). In the present study, white-chinned petrels attended the fishing vessel in 96 % of the sets, resulting in a bycatch rate of 0.181–1.042. Notably, all birds caught at night were white-chinned petrels. The distribution of these petrels in our study extended 5° farther north than that recorded by the IUCN; however, their sightings were less abundant north of 32°S. Therefore, the IUCN should consider expanding the distribution range of white-chinned petrels to reflect their broader presence.

The spectacled petrel, similar to the white-chinned petrel, is a medium-sized procellariiform abundant in waters around 30°S. In this study, the extent of abundance and the rate of attack were higher for spectacled petrels than for white-chinned petrels. However, the bycatch rate was lower for spectacled petrels than for white-chinned petrels. This finding is consistent with those of studies indicating a lower bycatch rate for spectacled petrels than for white-chinned petrels (Bugoni et al., 2008; Jimenez et al., 2010). The relatively low bycatch rate for spectacled petrels may be attributable to their feeding behaviors, such as pulling and dragging bait rather than swallowing it directly. The spectacled petrel is classified as a critically endangered species because of its small population size and high susceptibility to bycatch in longline fisheries (Ryan et al., 2006).

In our study, 100 % of great shearwaters and 62.5 % of black-browed albatrosses were caught in April and May in areas located south of 35°S, where these species were abundant. Great shearwaters exhibit distinct spatiotemporal distribution patterns and aggressive bait-attacking behaviors (Jimenez et al., 2011). Once great shearwaters attended our fishing vessel, they became the predominant bycatch species, with bycatch rates ranging from 0.362 to 1.268, corresponding to their high attack rates. Black-browed albatrosses are commonly caught as incidental bycatch during commercial fishing operations (Robertson et al., 2014). In this study, the bycatch rate for black-browed albatrosses ranged from 0.554 to 2.899 birds per 1000 hooks - among the highest rates ever recorded, underscoring the urgent need for effective mitigation in this fishery.

In this study, longitude, latitude, temperature, and month were used as spatial-temporal predictors related to seabird distribution patterns. Our GLM analysis indicated that the bycatch rates for great shearwaters, yellow-nosed albatrosses (Atlantic), and spectacled petrels were significantly associated with these environmental and temporal predictors, which likely reflect seabird abundance. The distributions of sighted seabirds belonging to these species (Fig. 2) provided a reasonable explanation for this association. For instance, the higher numbers of great shearwaters sighted in areas with eastern longitude and low temperatures explained their higher bycatch rates in these regions. The GLM analysis further suggested that the use of weighted branch lines effectively reduced the bycatch of species such as the white-chinned petrel and black-browed albatross, which exhibited aggressive bait-attacking behaviors.

4.2. Attack behavior

Of the six primary seabird species caught as bycatch, three belonged to the diving guild, exhibiting both primary and secondary attack behaviors, whereas the other three (albatrosses) belonged to the surface-feeding guild, exhibiting secondary attack behaviors. Among the seabird species caught in this study, the great shearwater was the most aggressive and competitive one. Their foraging behavior, supported by their ability to dive to depths of up to 18.9 m (Ronconi et al., 2010), provides them with a competitive advantage over other species, such as the white-chinned petrel, which typically dives to 5 or 6 m but can reach depths of up to 13 m (Berrow et al., 2000; Huin, 1994). This diving ability likely contributed to great shearwaters being the most prevalent bycatch species in our study when they were part of the attending seabird assemblage, consistent with their high attack rates and competitive behavior. Although black-browed albatrosses are generally regarded as surface feeders, they can dive to depths of up to 2.5 m (Anderson and Mcardle, 2002) and exhibit primary attack behaviors.

Our findings support the hypothesis that different seabird assemblages exhibit different levels of hierarchical and competitive behaviors at both species and individual levels (Jimenez et al., 2011). High-resolution data on seabird–vessel interactions and bycatch rates are essential for understanding the species-specific effects of fisheries on seabirds (Votier et al., 2023). These effects vary depending on the seabird genus. Strong associations were observed between seabird abundance, attack behaviors, and bycatch rates. In general, attack rates were proportional to species sightings; however, certain species, such as the great shearwater and black-browed albatross, exhibited disproportionately high levels of aggression. Conversely, species such as the cape petrel were less aggressive than others. Furthermore, the risk of bycatch varied by species: white-chinned petrels were more likely than others to be caught, whereas spectacled petrels were less likely (despite making frequent attacks) than others to be caught. These findings suggest that species-specific behavioral traits significantly influence bycatch rates, highlighting the complex dynamics between seabird aggression and fishing operations (Bentley et al., 2021).

4.3. Effectiveness of mitigation measures

The effectiveness of various BSL-based mitigation measures in reducing bycatch rates is influenced by factors such as deployment, gear configuration, and fishing operations (Jiménez et al., 2020; Melvin et al., 2014; Sato et al., 2012). In our study, no seabird attacks occurred in areas covered by BSLs. Notably, the fishing crew of the study vessel often customized the BSLs by using materials available onboard; this introduced variability in the streamer length. Although the experimental design (RFMO-recommended; ICCAT Recommendation 11–09) was found to be more effective than the conventional design in altering the distribution and frequency of seabird attack behaviors, it did not result in a statistically significant reduction in seabird bycatch. In this study, the effectiveness of bird-scaring lines (BSLs) appeared to be primarily influenced by the length of the mainline: the conventional mainlines were approximately 65 m long, whereas the experimental mainlines were 125 m long. It is important to note that none of the BSLs deployed in this study achieved the ICCAT-recommended 100 m aerial extent. This deviation from the guidelines likely limited the effectiveness of the BSLs and may explain the lack of significant differences in bycatch rates among BSL treatments. Beyond the limited aerial coverage, baited hooks remained at depths accessible to seabirds. Therefore, variations in BSL aerial extent may have shifted the spatial location of potential seabird attacks—either closer to or farther from the stern—rather than substantially reducing the overall accessibility of baited hooks. These results underscore the importance of adhering to standardized mitigation guidelines to ensure effective bycatch reduction.

In our study, seabird attacks rarely occurred in the astern area when baited hooks had sunk deeper than 5 m. When hooks were still shallower than 5 m, attacks were concentrated in the astern area not covered by BSLs. Therefore, bycatch mitigation measures for seabird assemblages in the southeastern Atlantic should focus on protecting the astern area, particularly when baited hooks are within the upper 5 m of the water column.

Regardless of branch line weighting, the sink rates in this study were slower than those reported by Melvin et al. (2014). During normal fishing operations, the unweighted hooks reached a mean depth of 5.57 m within 30 s, whereas the weighted hooks reached a mean depth of 13.44 m in the same period. By contrast, the weighted branch lines reached a mean depth of 10 m within 40 s, with a sink rate of 0.3 m/s; this finding aligns with that of a study conducted in waters surrounding New Zealand (Anderson and Mcardle, 2002). Our use of weighted branch lines increased the sink rate by up to 32 % at shallower depths, effectively reducing the risk of seabird bycatch.

Night setting is a widely used and effective measure for mitigating seabird bycatch (Gilman et al., 2023; Løkkeborg, 2008). Its effectiveness is attributable to the fact that many seabirds are most active around dawn and dusk (BirdLife International Global Seabird Programme, 2009). Melvin et al. (2014) combined multiple mitigation measures and found that seabird bycatch rates were > 13 times higher during daytime (0.378 birds per 1000 hooks) than during nighttime (0.028 birds per 1000 hooks). In a subsequent study, Melvin et al. (2014) demonstrated that the bycatch rate for white-chinned petrels was 4.6 times higher during daytime (2.00 birds per 1000 hooks) than during nighttime (0.439 birds per 1000 hooks). We found that the bycatch rate for all bird species was much higher during the daytime than during nighttime. These results highlight the effectiveness of night setting as a bycatch mitigation measure, also for species such as the white-chinned petrel, which are active at night. However, while NightSR was not a significant variable in explaining seabird bycatch rates—except for the spectacled petrel—this does not imply that night setting is ineffective as a mitigation measure. In our study, NightSR represents the proportion of hooks set at night during each fishing operation, rather than soak time. The average

NightSR was 0.35 (SD = 0.19), indicating a relatively consistent fishing pattern in which about one-third of hooks were deployed at night. This limited variation may explain the lack of a statistically significant association with bycatch rates. Moreover, our data showed that only 6 seabirds were caught on hooks set at night, compared to 292 caught on hooks set during the day. This finding suggests that modest levels of night setting may not be sufficient to substantially reduce seabird bycatch, and that a more comprehensive implementation—i.e., setting all hooks at night—may be required to achieve meaningful mitigation. Besides, in our study, 18 incidents of seabird bycatch were recorded during hauling. All seabirds were released alive. Our findings indicate a need for the development of mitigation measures that specifically target the hauling process to enhance the overall effectiveness of bycatch mitigation (Gilman et al., 2014).

Comparing our study's findings with previous research on seabird bycatch rates in similar fisheries. Huang et al. (2009) provides estimates of seabird incidental catch by pelagic longline fisheries in the South Atlantic Ocean. This study analyzed data from fishery observers over a five-year period, covering 61 trips and 6181 observed sets, with over 20 million hooks deployed. It reported seabird bycatch rates ranging from 0.026 to 0.063 birds per thousand hooks, with hotspots identified at 20°–40°S/10°W–15°E and 35°–45°S/45°–55°W.

Compared to these findings, our study observed similar species compositions in the southeastern Atlantic Ocean. However, a key distinction is that our sample vessel operated within the bycatch hotspot identified in Huang et al. (2009), resulting in significantly higher seabird bycatch rates. Moreover, the vessel used conventional, self-made bird-scaring lines (BSLs), which were commonly employed by the fleet prior to the implementation of standardized BSL regulations in 2008. These results demonstrate the importance of adhering to internationally recommended mitigation standards, such as those outlined by ICCAT and ACAP, rather than relying on locally adapted or convenient practices.

In interpreting the effectiveness of mitigation measures, it is important to acknowledge that none of the BSLs used in this study achieved the ICCAT-recommended aerial extent of 100 m for vessels longer than 35 m. Furthermore, the proportion of hooks set during nighttime was insufficient to qualify as "night setting" under ICCAT definitions. These deviations from international guidelines should be made explicit, as they may have limited the overall effectiveness of mitigation measures and contributed to the absence of statistically significant differences among BSL treatments. Thus, while the study provides valuable behavioral insights, the results must be interpreted within the context of these limitations.

4.4. Effect on target catch

The challenge of balancing a reduction in seabird bycatch with maintenance of target catch rates complicates fisheries management. Several studies have highlighted the intricacy of this problem and obtained mixed results regarding the effectiveness and implications of bycatch mitigation measures. Gilman et al. (2023) analyzed data from the electronic monitoring system of a pelagic longline fishery in the Pacific Ocean and found that the combination of nighttime setting and deep fishing effectively reduced the risk of seabird bycatch without significantly affecting the target catch rate. These findings align with those of a study indicating no negative effect of mitigation measures on target species (Løkkeborg and Robertson, 2002) and those of another study indicating elevated catch rates and reduced bait loss under similar conditions (Løkkeborg, 2003). Many studies have indicated that some mitigation measures exert no or even positive effects on target species catch (Avery et al., 2017).

Melvin et al. (2014) reported that the use of weighted branch lines had no statistically significant effect on the overall catch rate of target species. While the mean catch rate of albacore was lower in the treatment group, this difference was not tested statistically, as albacore was not a target species and was caught in low numbers. Gilman et al. (2022) highlighted potential trade-offs associated with seabird bycatch mitigation. In the US North Pacific tuna longline fishery, the use of weighted hooks led to a 53 % reduction in target species catch, despite sink rates increasing. Similarly, we observed a significant reduction in albacore catch when weighted branch lines were used. From the fishers' perspective, this reduction is primarily attributable to reduced bait mobility, which limits the bait's ability to attract fish.

Our findings underscore the need for a careful evaluation of the effects of mitigation measures on target species. Although such measures can effectively reduce seabird bycatch, their potential negative effect on target species catch cannot be overlooked. The variability in the findings regarding treatment outcomes suggests that the effects of mitigation measures vary depending on factors such as gear configuration, target species, and fishing location, indicating a need for well-designed, nuanced, and adaptable mitigation measures. Our results indicate that soak time significantly influenced albacore catch rates in the daytime setting subgroup, but not in the nighttime subgroup. This implies that beyond a soak time of four hours, its effect on catch rates becomes negligible. These insights may inform the optimization of future experimental designs.

Interviews were conducted with the fishing crew after the experiment of this study. In general, the crew members were eager to reduce seabird bycatch, partly to avoid the labor and bait loss associated with managing bycatch. However, they were concerned about the potential negative effects of mitigation measures on target species such as albacore. Although reducing seabird bycatch might help minimize bait loss, fishers contemplating adopting mitigation measures prioritized their economic implications, particularly their effects on target species catch. This highlights the importance of developing measures that balance the goal of seabird conservation with the economic viability of fishing operations.

5. Conclusion

Our findings suggest that the use of weighted branch lines and appropriate BSLs significantly reduced seabird bycatch in longline fisheries. The present study demonstrated that the use of weighted branch lines was associated with 77 %, 36 %, and 61 % reductions in the bycatch rates for white-chinned petrels, black-browed albatrosses, and all seabirds, respectively, confirming the effectiveness of this measure. To optimize bycatch reduction efforts, fishing operations must also consider the diving capabilities of seabirds and the aerial coverage of BSLs.

Night setting effectively reduced seabird bycatch per unit effort, although exceptions exist for certain species, such as the northern fulmar (Melvin et al., 2019; Sánchez and Belda, 2003). In the present study, approximately one-third of all setting operations occurred at night, resulting in a bycatch rate considerably lower than that during daytime operations. However, many fisheries found it difficult to complete an entire set at night (Melvin et al., 2014; Orbesen et al., 2017). Notably, night setting was typically combined with other mitigation measures to further reduce seabird bycatch.

Until now, after RFMOs adopted regulations seeking to achieve reductions in levels of seabird bycatch, numerous measures for mitigating seabird bycatch have been tested and implemented across fisheries. In the present study, we examined the impact of fishing operations using only bird-scaring lines and the benefits derived from the additional use of a second mitigation measure alongside bird-scaring line on pelagic albacore longline vessels. Our findings not only confirmed the effectiveness of the combined measures but also clarified the behavior of various seabird species in the southern Atlantic Ocean. We further analyzed the temporal variations in seabird assemblages associated with the study fishery and evaluated their foraging interactions.

Despite mitigation measures success, a concern emerged during hauling operations: trolling lines used to catch albacore carried a risk of seabird bycatch. Thus, mitigation measures tailored to hauling operations must be developed to minimize seabird bycatch during this phase.

Although mitigation measures hold promise in reducing seabird bycatch, their potential negative effect on target species catch must be addressed. Continual evaluation and adaptation are necessary to strike a balance between reducing seabird bycatch and maintaining target catch rates. Fishers' concerns, particularly those regarding economic viability and catch efficiency, must be addressed to facilitate the long-term implementation of mitigation measures.

We could not proactively determine the fishing days and operational areas for the commercial fishing vessel considered in this study because of uncertainties in actual catch conditions and weather. Moreover, the captain's concerns about the effect of weighted branch lines on albacore catch imposed limitations on the experimental design, further complicating subsequent statistical analyses. Furthermore, fishers expressed reluctance to modify the BSL design to increase aerial coverage, such as extending the mainline or attaching a float at the end to increase drag. They were concerned that the increased tension might cause the tori pole or the BSL mainline to break, disrupting fishing operations. Additionally, maintaining vessel speed to counteract the increased drag could raise fuel consumption, which was also considered unacceptable.

CRediT authorship contribution statement

Huan-Chang Liao: Project administration, Investigation. **Hsiang-Wen Huang:** Writing – review & editing, Validation, Supervision, Project administration, Conceptualization. **Yu-Min Yeh:** Writing – original draft, Visualization, Validation, Supervision, Project administration, Methodology, Formal analysis, Data curation, Conceptualization. **Shu-Chun Chen:** Writing – review & editing, Methodology, Formal analysis. **Ting-Chun Kuo:** Writing – review & editing, Funding acquisition.

Ethical Statement

This study was conducted in accordance with institutional and national guidelines for the ethical treatment of animals. All data on seabird bycatch and behavior were collected through on-board observations aboard a commercial Taiwanese albacore longline fishing vessel, with the full cooperation of the fishing crew. Observers did not intentionally capture or harm seabirds for research purposes. However, when seabirds were incidentally caught during fishing operations, trained observers followed standard handling protocols to recover and identify dead specimens and to release any live birds in a manner that minimized further stress or injury. All procedures were non-invasive and aligned with ethical practices for wildlife research at sea. Data collection was carried out under appropriate permits, and no additional animal experimentation requiring institutional animal care and use committee (IACUC) approval was involved.

Declaration of generative AI and AI-assisted technologies in the writing process

ChatGPT was used to improve the readability and language of the manuscript. After manuscript preparation, the authors reviewed and edited the content to ensure accuracy. The authors agree to take full responsibility for the content of the manuscript.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

This work is dedicated to the memory of Yu-Huai Wang, whose contribution of time–depth recorders and professional support was instrumental to this study. We are also deeply grateful to all the fieldworkers who participated in the data collection. Special thanks go to the staff at the Data Science Statistical Cooperation Center, Academia Sinica, for their assistance with statistical analyses. We also appreciate the constructive comments and feedback provided by three anonymous reviewers, as well as by Dr. Stephanie Prince, Mr. Alan Munro, and Mr. Scott Pursner. This manuscript was edited by Wallace Academic Editing.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.gecco.2025.e03752.

Data availability

Data will be made available on request.

References

ACAP, 2024. Review of mitigation measures and best practice advice for reducing the impact of pelagic longline fisheries on seabirds reviewed at the fourteenth meeting of the advisory committee. Lima Peru. 12–16. August 2024.
Anderson, O.R.J., Small, C.J., Croxall, J.P., Dunn, E.K., Sullivan, B.J., Yates, O., Black, A., 2011. Global seabird bycatch in longline fisheries. Endanger. Species Res. 14, 91–106.
Anderson, S., Mcardle, B., 2002. Sink rate of baited hooks during deployment of a pelagic longline from a New Zealand fishing vessel. N. Z. J. Mar. Freshw. Res. 36, 185–195.
Avery, J.D., Aagaard, K., Burkhalter, J.C., Robinson, O.J., 2017. Seabird longline bycatch reduction devices increase target catch while reducing bycatch: A meta-analysis. J. Nat. Conserv. 38, 37–45.
Baker, G.B., Wise, B.S., 2005. The impact of pelagic longline fishing on the flesh-footed shearwater *Puffinus carneipes* in Eastern Australia. Biol. Conserv. 126, 306–316.
Bentley, L.K., Kato, A., Ropert-Coudert, Y., Manica, A., Phillips, R.A., 2021. Diving behaviour of albatrosses: implications for foraging ecology and bycatch susceptibility. Mar. Biol. 168.
Berrow, S.D., Wood, A.G., Prince, P.A., 2000. Foraging location and range of White-chinned Petrels Procellaria aequinoctialis breeding in the South Atlantic. J. Avian Biol. 31, 303.
BirdLife International Global Seabird Programme, 2009. Analysis of Seabird Measures. In Scientific Committe Fifth Regular Session. WCPFC, Port Vila, Vanuatu.
Breslow, N., 1990. Biostatistics and Bayes. Stat. Sci. 5, 269–284.
Bugoni, L., Neves, T.S., Leite Jr, N.O., Carvalho, D., Sales, G., Furness, R.W., Stein, C.E., Peppes, F.V., Giffoni, B.B., Monteiro, D.S., 2008. Potential bycatch of seabirds and turtles in hook-and-line fisheries of the Itaipava Fleet, Brazil. Fish. Res. 90, 217–224.
Calado, J.G., Ramos, J.A., Almeida, A., Oliveira, N., Paiva, V.H., 2021. Seabird-fishery interactions and bycatch at multiple gears in the Atlantic Iberian coast. Ocean Coast. Manag. 200, 105306.
Collins, M.A., Hollyman, P.R., Clark, J., Soeffker, M., Yates, O., Phillips, R.A., 2021. Mitigating the impact of longline fisheries on seabirds: lessons learned from the South Georgia Patagonian toothfish fishery (CCAMLR Subarea 48.3). Mar. Policy 131.
FAO, 1999. Interanal Plan of Action for reduing incidental catch of seabirds in longline fisheries.
Favero, M., Seco Pon, J.P., 2014. Challenges in seabird by-catch mitigation. Anim. Conserv. 17, 532–533.
Fisheries Agency, C.o.A., Executive Yuan, Taiwan (R.O.C), 2014. Taiwan's National Plan of Action for Reducing Incidental Catch of Seabirds in Tuna Longline Fisheries. James Sha, Taiwan.
Geernaert, T.O., 1999. The Recovery of the Short-tailed Albatross and its Impacts on the North Pacific Longline Fishery, In Proceedings of a Conference on the Biology and Management of Species and Habitats at Risk. ed. L.M. Darling, p. 490pp. B.C. Ministry of Environment, Lands and Parks, Victoria, B.C. and University College of the Cariboo, Kamloops, B.C., Kamloops, B.C.
Gilman, E., Kobayashi, D., Chaloupka, M., 2008. Reducing seabird bycatch in the Hawaii longline tuna fishery. Endanger. Species Res. 5, 309–323.
Gilman, E., Chaloupka, M., Wiedoff, B., Willson, J., 2014. Mitigating seabird bycatch during hauling by pelagic longline vessels. PLoS ONE 9, e84499.
Gilman, E., Musyl, M., Wild, M., Rong, H., Chaloupka, M., 2022. Investigating weighted fishing hooks for seabird bycatch mitigation. Sci. Rep. 12, 2833.
Gilman, E., Evans, T., Pollard, I., Chaloupka, M., 2023. Adjusting time-of-day and depth of fishing provides an economically viable solution to seabird bycatch in an albacore tuna longline fishery. Sci. Rep. 13, 2621.
Huang, H.W., Yeh, Y.M., 2011. Impact of Taiwanese distant water longline fisheries on the Pacific seabirds: finding hotspots on the high seas. Anim. Conserv. 14, 562–574.
Huang, H.-W., Chang, K.-y, Tai, J.-P., 2009. The impact of Taiwanese longline fisheries on seabirds in the Atlantic Ocean. In SCRS. ICCAT, pp. 2398–2404.
Huin, N., 1994. Diving depths of white-chinned petrels. Condor 96, 1111–1113.
IUCN, 2001. IUCN Red List Categories and Criteria: Version 3.1. IUCN Species Survival Commission. IUCN, Gland, Switzerland and Cambridge, UK. ii + 30 pp.
ICCAT, 2011. Supplemental recommendation by ICCAT on reducing incidental by-catch of seabirds in ICCAT fisheries.
Jimenez, S., Abreu, M., Pons, M., Ortiz, M., Domingo, A., 2010. Assessing the impact of the pelagic longline fishery on albatrosses and petrels in the southwest Atlantic. Aquat. Living Resour. 23, 49–64.
Jimenez, S., Domigo, A., Abreu, M., Brazeiro, A., 2011. Structure of the seabird assemblage associated with pelagic longline vessels in the southwestern Atlantic: implications for bycatch. Endang Species Res. 15, 241–254.
Jiménez, S., Domingo, A., Winker, H., Parker, D., Gianuca, D., Neves, T., Coelho, R., Kerwath, S., 2020. Towards mitigation of seabird bycatch: large-scale effectiveness of night setting and Tori lines across multiple pelagic longline fleets. Biol. Conserv. 247, 108642.
Lewison, R.L., Crowder, L.B., Read, A.J., Freeman, S.A., 2004. Understanding impacts of fisheries bycatch on marine megafauna. Trends Ecol. Evol. 19, 598–604.
Li, Y., Jiao, Y., Browder, J.A., 2016. Modeling spatially-varying ecological relationships using geographically weighted generalized linear model: a simulation study based on longline seabird bycatch. Fish. Res. 181, 14–24.
Løkkeborg, S., 2003. Review and evaluation of three mitigation measures—bird-scaring line, underwater setting and line shooter—to reduce seabird bycatch in the north Atlantic longline fishery. Fish. Res. 60, 6–11.
Løkkeborg, S., 2008. Review and assessment of mitigation measures to reduce incidental catch of seabirds in longline,rawl and gillnet fisheries. FAO Fish. Aquac. Circ. 1040.
Løkkeborg, S., Robertson, G., 2002. Seabird and longline interactions: effects of a bird-scaring streamer line and line shooter on the incidental capture of northern fulmars. Biol. Conserv. 106, 359–364.
Melvin, E.F., Parrish, J.K., Conquest, L.L., 1999. Novel Tools to Reduce Seabird Bycatch in Coastal Gillnet Fisheries. Conserv. Biol. 13, 12.
Melvin, E.F., Sullivan, B., Robertson, G., Wienecke, B., 2004. A review of the effectiveness of streamer lines as a seabird by-catch mitigation technique in longline fisheries and CCAMLR streamer line requirements. Ccamlr Sci. 11, 189–201.

Melvin, E.F., Guy, T.J., Read, L.B., 2013. Reducing seabird bycatch in the South African joint venture tunafishery using bird-scaring lines, branch line weighting andnighttime setting of hooks. Fish. Res. 147, 72–82.
Melvin, E.F., Guy, T.J., Read, L.B., 2014. Best practice seabird bycatch mitigation for pelagic longline fisheries targeting tuna and related species. Fish. Res. 149, 5–18.
Melvin, E.F., Dietrich, K.S., Suryan, R.M., Fitzgerald, S.M., 2019. Lessons from seabird conservation in Alaskan longline fisheries. Conserv. Biol. 33, 842–852.
Melvin, E.F., Wolfaardt, A., Crawford, R., Gilman, E., Suazo, C.G., 2023. Chapter 17 - Bycatch reduction. In: Young, L., VanderWerf, E. (Eds.), Conservation of Marine Birds. Academic Press, pp. 457–496.
Oliveira, N., Henriques, A., Miodonski, J., Pereira, J., Marujo, D., Almeida, A., Barros, N., Andrade, J., Marçalo, A., Santos, J., Oliveira, I.B., Ferreira, M., Araújo, H., Monteiro, S., Vingada, J., Ramírez, I., 2015. Seabird bycatch in Portuguese mainland coastal fisheries: an assessment through on-board observations and fishermen interviews. Glob. Ecol. Conserv. 3, 51–61.
Orbesen, E.S., Snodgrass, D., Shideler, G.S., Brown, C.A., Walter, J.F., 2017. Diurnal patterns in Gulf of Mexico epipelagic predator interactions with pelagic longline gear: implications for target species catch rates and bycatch mitigation. Bull. Mar. Sci. 93, 573–589.
Phillips, R.A., Silk, J.R.D., Croxall, J.P., Afanasyev, V., 2006. Year-round distribution of white-chinned petrels from South Georgia: relationships with oceanography and fisheries. Biol. Conserv. 129, 336–347.
Proceedings of the Symposium, 2001. Seabird Bycatch Trends, Roadblocks, and Solutions, In Annual Meeting of the Pacific Seabird Group. eds E.F. Melvin, J.K. Parrish, p. 204, Blaine, Washington.
Richards, C., Cooke, R.S.C., Bates, A.E., 2020.
Richards, C., Cooke, R., Bowler, D.E., Boerder, K., Bates, A.E., 2024. Bycatch-threatened seabirds disproportionally contribute to community trait composition across the world. Glob. Ecol. Conserv. 49, e02792.
Robertson, G., McNeill, M., Smith, N., Wienecke, B., Candy, S., Olivier, F., 2006. Fast sinking (integrated weight) longlines reduce mortality of white-chinned petrels (*Procellaria aequinoctialis*) and sooty shearwaters (*Puffinus griseus*) in demersal longline fisheries. Biol. Conserv. 132, 458–471.
Ryan, P.G., Dorse, C., Hilton, G.M., 2006. The conservation status of the spectacled petrel Procellaria conspicillata. Biological Conservation 131 (4), 575–583. https://doi.org/10.1016/j.biocon.2006.03.004.
Robertson, G., Candy, S.G., Wienecke, B., Lawton, K., 2010. Experimental determinations of factors affecting the sink rates of baited hooks to minimize seabird mortality in pelagic longline fisheries. Aquat. Conserv. Mar. Freshw. Ecosyst. 20, 632–643.
Robertson, G., Candy, S.G., Hall, S., 2013. New branch line weighting regimes to reduce the risk of seabird mortality in pelagic longline fisheries without affecting fish catch. Aquat. Conserv. Mar. Freshw. Ecosyst. 23, 885–900.
Robertson, G., Moreno, C., Arata, J.A., Candy, S.G., Lawton, K., Valencia, J., Wienecke, B., Kirkwood, R., Taylor, P., Suazo, C.G., 2014. Black-browed albatross numbers in Chile increase in response to reduced mortality in fisheries. Biol. Conserv. 169, 319–333.
Rollinson, D.P., Wanless, R.M., Ryan, P.G., 2017. Patterns and trends in seabird bycatch in the pelagic longline fishery off South Africa. Afr. J. Mar. Sci. 39, 9–25.
Ronconi, R.A., Ryan, P.G., Ropert-Coudert, Y., 2010. Diving of great shearwaters (Puffinus gravis) in cold and warm water regions of the South Atlantic Ocean. PLoS ONE 5, 1–7.
Ryan, P., Dilley, B., Jones, M., 2012. The distribution and abundance of white-chinned petrels (*Procellaria aequinoctialis*) breeding at the sub-Antarctic Prince Edward Islands. Polar Biol. 35, 1851–1859.
Sánchez, A., Belda, E.J., 2003. Bait loss caused by seabirds on longline fisheries in the northwestern Mediterranean: is night setting an effective mitigation measure? Fish. Res. 60, 99–106.
Sato, N., Ochi, D., Minami, H., Yokawa, K., 2012. Evaluation of the effectiveness of light streamer tori-lines and characteristics of bait attacks by seabirds in the Western North Pacific. PLoS ONE 7.
Sato, N., Minami, H., Katsumata, N., Ochi, D., Yokawa, K., 2013. Comparison of the effectiveness of paired and single tori lines for preventing bait attacks by seabirds and their bycatch in pelagic longline fisheries. Fish. Res. 140, 14–19.
Sato, N., Katsumata, N., Yokota, K., Uehara, T., Fusejima, I., Minami, H., 2016. Tori-lines with weighted branch lines reduce seabird bycatch in eastern South Pacific longline fishery. Aquat. Conserv. Mar. Freshw. Ecosyst. 26, 95–107.
Seco Pon, J.P., Gandini, P.A., Favero, M., 2007. Effect of longline configuration on seabird mortality in the Argentine semi-pelagic Kingclip Genypterus blacodes fishery. Fish. Res. 85, 101–105.
Tamini, L.L., Chavez, L.N., Góngora, M.E., Yates, O., Rabuffetti, F.L., Sullivan, B., 2015. Estimating mortality of black-browed albatross (Thalassarche melanophris, Temminck, 1828) and other seabirds in the Argentinean factory trawl fleet and the use of bird-scaring lines as a mitigation measure. Polar Biol. 38, 1867–1879.
Tuck, G.N., Phillips, R.A., Small, C., Thomson, R.B., Klaer, N.L., Taylor, F., Wanless, R.M., Arrizabalaga, H., 2011. An assessment of seabird–fishery interactions in the Atlantic Ocean. ICES J. Mar. Sci. 68, 1628–1637.
Votier, S.C., Sherley, R.B., Scales, K.L., Camphuysen, K., Phillips, R.A., 2023. An overview of the impacts of fishing on seabirds, including identifying future research directions. ICES J. Mar. Sci. 80, 2380–2392.
Weimerskirch, H., Capdeville, D., Duhamel, G., 2000. Factors affecting the number and mortality of seabirds attending trawlers and long-liners in the Kerguelen area. Polar Biol. 23, 236–249.
Wilman, H., Belmaker, J., Simpson, J., de la Rosa, C., Rivadeneira, M.M., Jetz, W., 2014. EltonTraits 1.0: Species-level foraging attributes of the world's birds and mammals. Ecology 95, 2027, 2027.
Yeh, Y.M., Huang, H.W., Dietrich, K.S., Melvin, E., 2013. Estimates of seabird incidental catch by pelagic longline fisheries in the South Atlantic Ocean. Anim. Conserv. 16, 141–152.
Yokota, K., Minami, H., Kiyota., M., 2008. Direct comparisons of seabird avoidance effect between two types of tori-lines in experimental longline operations., In WCPFC-SC4-2008/EB-WP-7.

SUSTAINABLE DEVELOPMENT GOALS

南華大學
Nanhua University http://www.nhu.edu.tw/ 62249嘉義縣大林鎮南華路一段55號 05-3102100