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New records of marine fishes illustrate the biogeographic importance of Christmas Island, Indian Ocean

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Abstract

Christmas Island is situated in the tropical eastern Indian Ocean on a biogeographic border where Indian and Pacific Ocean faunas meet. Detailed field studies in 2004, 2007 and 2008, of the island's fish fauna revealed 30 new records from 15 families. For six families (Dasyatidae, Chanidae, Bramidae, Mugilidae, Siganidae, Molidae) this is the first time a species has been recorded at Christmas Island. Many of the newly recorded fishes appear to have recently colonised the island, and establishing populations will be dependent on the availability of suitable habitat and conspecific mates. These new records illustrate that Christmas Island is important for range expansion because it serves as a critical stepping-stone in the dispersal of Pacific Ocean species into the Indian Ocean and vice versa. Contact between Indian and Pacific Ocean sister species has also resulted in hybridisation at Christmas Island.

Key words:

Introduction

Christmas Island (10°30' S, 105°40' E) is an isolated, oceanic island located in the tropical, eastern Indian Ocean approximately 360 km south of Java, Indonesia (Figure 1). The island lies on the Indo-Pacific biogeographic border, and appears to represent an area of secondary contact between Indian and Pacific Ocean regional faunas (Hobbs and Salmond 2008; Hobbs et al. 2009), that were once separated by land bridges in Indonesia (Sunda Shelf Barrier: Randall 1998; Rocha *et al.* 2007). Given the unique position of this island, we decided to conduct an extensive investigation of the fish fauna to identify new records that may help reveal what role the island plays in the biogeography of tropical marine fishes.

The fish fauna of Christmas Island was surveyed in February and March 2004, February 2007 and from February to November 2008. Surveys were done almost every day during fieldtrips in 2004 and 2007, and approximately every second day during the 2008 fieldtrip. Fishes were observed whilst snorkelling in shallow waters (0–5 m) and SCUBA diving in deeper waters (5–70 m). Collectively, more than 400 SCUBA dives were undertaken and involved a combination of exploratory dives to 70 m and formal underwater visual censuses (replicate 50 by 5 m transects) conducted at 5 and 20 m depth. Over 52 different sites were examined around the full extent of the island (north, south, east and west coasts). Species were only recorded where visual identification was certain. In most cases, species were photographed to confirm identification. In

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addition, catches by local people from deep slope line fishing activities were also examined. A species was considered to be a new record if it was not on the "Checklist of Christmas Island fishes" (Allen *et al.* 2007).

Allen *et al.* (2007) estimated 592 fish species from 75 families have been recorded at Christmas Island. The 30 new records (from 15 families) reported in this study (Table 1) increase the total number of fish species to 622 from 80 families. This is the first time a species has been recorded at Christmas Island for the following six families: Dasyatidae, Chanidae, Bramidae, Mugilidae, Siganidae, Molidae. The new records represent a cosmopolitan group covering a range of families, body sizes, habitats and geographic distributions (Table 1).

TABLE 1. New marine fish records from Christmas Island based on underwater observations made from 2004-2008. The geographic distribution of each new record is presented as numbers following Allen & Smith-Vaniz (1994), where "1 = widespread Indo-Pacific or Indo-west Pacific; 2 = West Pacific species that reach their western distributional limit at Cocos (Keeling) [or Christmas Island]; 3 = Indian Ocean species (may include western extremity of west Pacific); 4 = Circumtropical or cosmopolitan." Species that are also known from the Cocos (Keeling) Islands are denoted by *. Information on geographic ranges is based on Allen & Smith-Vaniz (1994), Allen *et al.* (2007), Froese & Pauly (2007).

Species	Family	Location	Abundance	Distribution	Depth (m)
Carcharhinus falciformis (Müller & Henle)	Carcharhinidae	North coast	Common (>30)	4*	Surface waters in open ocean
Taeniura meyeni Müller & Henle	Dasyatidae	North coast	1	1	15
Chanos chanos (Forsskål)	Chanidae	North coast	8	1*	5–10
Sargocentron spiniferum (Forsskål)	Holocentridae	North coast	2	1*	30–40
Pseudanthias pleurotaenia (Bleeker)	Serranidae	MV Eidsvold shipwreck	20 - 30	2	40–50
Epinephelus fuscoguttatus (Forsskål)	Serranidae	Flying Fish Cove	1	1*	25
Epinephelus octofasciatus Griffin	Serranidae	West coast	1	1	200
Variola albimarginata Baissac	Serranidae	North and west coast	5	1	30–80
Brama australis Valenciennes	Bramidae	North coast	1	4, subtropical	>100
Lethrinus xanthochilus Klunzinger	Lethrinidae	The Dales, West coast	1	1*	12
Lethrinus erythropterus Valenciennes	Lethrinidae	North coast	2	1*	15–20
Chaetodon bennetti Cuvier	Chaetodontidae	North coast	1	1*	20
Chaetodon lunulatus Quoy & Gaimard	Chaetodontidae	Flying Fish Cove	10	2	2–10
Heniochus acuminatus (Linnaeus)	Chaetodontidae	North coast	2	1	40
Centropyge colini Smith-Vaniz & Randall	Pomacanthidae	Rhoda Beach	1	2*	65
Genicanthus melanospilos (Bleeker)	Pomacanthidae	MV Eidsvold shipwreck	1	2	50

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TABLE 1. (continued)

Species	Family	Location	Abundance	Distribution	Depth (m)
Paracentropyge multifasciata (Smith & Radcliffe)	Pomacanthidae	Flying Fish Cove	1	2*	40
Pomacentrus alleni Burgess	Pomacentridae	North and west coasts	Common (>30)	Indonesia, Thailand	5–30
Pomacentrus moluccensis Bleeker	Pomacentridae	Flying Fish Cove	2	2	2
Crenimugil crenilabis (Forsskål)	Mugilidae	Flying Fish Cove	2	1*	2
Bodianus bilunulatus (Lacepède)	Labridae	North and west coasts	4	Disjointed Indo-Pacific	5–25
Chlorurus enneacanthus (Lacepède)	Labridae	North coast	2	3*	2–15
Chlorurus strongylocephalus (Bleeker)	Labridae	North coast	20–30	3*	5–15
Chlorurus capistratoides (Bleeker)	Labridae	North coast	4–8	3	2–10
Scarus tricolor Bleeker	Labridae	North coast	4–8	1	20–40
Acanthurus tennentii Günther	Acanthuridae	North coast	1	3	5–10
Acanthurus tristis Randall	Acanthuridae	North and west coasts	6	3	15–30
Naso caesius Randall & Bell	Acanthuridae	North and west coasts	Common (>30)	2	5–30
Siganus corallinus (Valenciennes)	Siganidae	MV Eidsvold shipwreck	1	1	5
Mola mola (Linnaeus)	Molidae	North coast	2	4	Surface waters in open ocean

Given the extensive surveys conducted previously (Allen *et al.* 2007), many of the newly recorded fishes, particularly those inhabiting shallow waters or that are easily recognisable, probably represent vagrants that have only recently colonised the island. For example, *Chaetodon rafflesi* is a conspicuous inhabitant of shallow coral reefs but it had never been observed at Christmas Island until 2005 when one individual was seen in an area that had been surveyed previously (Hobbs *et al.* 2007). In 2008, the same area was re-surveyed and eight individuals were observed, indicating that this recent colonist is becoming established. For recent colonists, establishing a breeding population at Christmas Island may be difficult if they are unable to locate suitable habitat or a conspecific partner.

Christmas Island does not have seagrass beds, coastal mangroves or lagoons and thus many taxa that require these habitats during their life cycle are rare or absent. For example, the entire family of rabbitfishes (Siganidae) is noticeably absent from the Island, although one individual was seen in 2008. Species such as *Siganus corallinus*, *Epinephelus fuscoguttatus*, *Lethrinus xanthochilus* and *Crenimugil crenilabis* utilise shallow inshore habitats (seagrass beds, mangroves or lagoons) when they are juveniles. The latter three species and four *Siganus* species are common at neighbouring Cocos (Keeling) Islands (authors' unpublished data and personal observations). The Cocos Islands are more isolated than Christmas Island, but contain a large lagoon with extensive sheltered, shallow-water habitat and seagrass beds. This indicates that lagoonal species are able to disperse to Christmas Island but have difficulty establishing populations due to the lack of sheltered, shallow-water habitat. Several new records were obtained in Flying Fish Cove (Figure 1), which is the most sheltered location on Christmas Island and this may provide marginal habitat for species that require lagoonal environments.

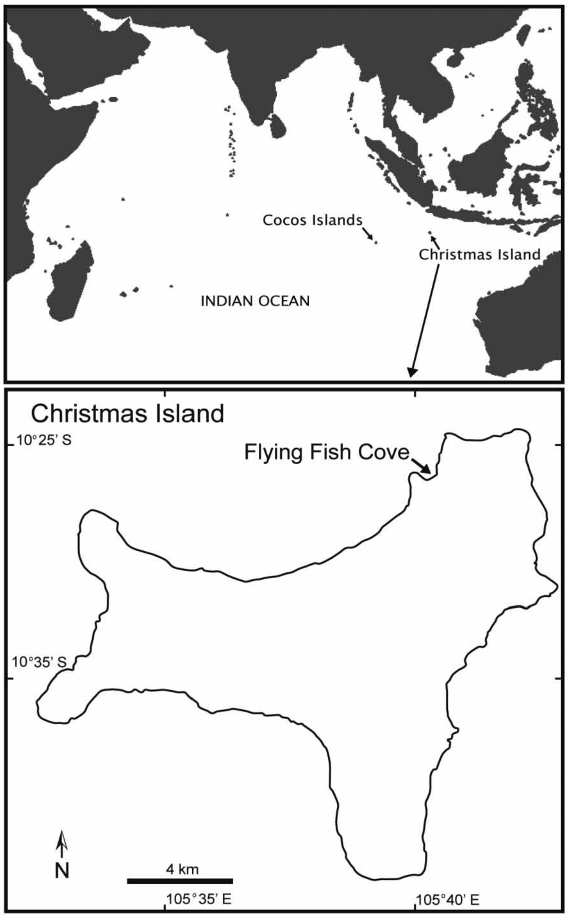

FIGURE 1. The location of Christmas Island and the Cocos (Keeling) Islands in the Indian Ocean. Inset: Christmas Island with the position of Flying Fish Cove indicated on the north coast.

In contrast to the new records, one species, the harlequin or longnose filefish (*Oxymonacanthus longirostris*), appears to have gone locally extinct at Christmas Island. This conspicuous shallow-water fish was recorded by Gerry Allen and Roger Steene during their earlier surveys (1978–1987: Allen *et al.* 2007). Despite intensive surveys in 2002, 2004, 2005, 2007 and 2008 we were unable to locate this species, and local divers had not seen this species during this period. The harlequin filefish feeds on *Acropora* corals, particularly branching forms, and these corals are currently in low abundance at Christmas Island. Habitat loss has led to severe declines and local extinctions of this filefish in other locations (Kokita & Nakazono 2001; Graham *et al.* 2006) and is the most likely explanation for its apparent extinction at Christmas Island.

The new records at Christmas Island represent range extensions for most species, the most notable being the westward expansion of Pacific Ocean species and the eastward expansion of Indian Ocean species. During past episodes of low sea level, land bridges arose throughout Indonesia forming the Sunda Shelf Barrier, which severely limited dispersal between the Indian and Pacific Oceans (Randall 1998; Rocha *et al.* 2007). Following Pleistocene ice ages, sea levels have risen to today's levels, allowing currents to flow through the Indonesian region, however successful dispersal of organisms between Indian and Pacific Oceans may be hindered by the large expanse of open ocean that lies immediately west of Indonesia. The only suitable coral reef habitat situated in this large expanse occurs at Christmas and Cocos Islands. Consequently, these islands act as important stepping-stones in the dispersal of organisms between Indian and Pacific Oceans. For example, *Acanthurus nigricans* is a Pacific Ocean species that has dispersed into the Indian Ocean and colonised Christmas and Cocos Islands. It has recently expanded its range further westward and has now colonised the central Indian Ocean (Craig, 2008).

The range expansion of Indian and Pacific Ocean species is causing allopatric sister species to come into contact at Christmas Island and this can have important ramifications. A scarcity of partners may lead a recent colonist to hybridise with a more common, sister species. For example, *Chaetodon lunulatus* is a Pacific Ocean species that appears to have recently colonised Christmas Island. This species was not recorded in previous surveys by G.R. Allen and R. Steene (1978–2006) who are experts on butterflyfish identification (Allen *et al.* 1998; Allen *et al.* 2007). The westward range expansion of *C. lunulatus* into the Indian Ocean, now puts it in contact with *C. trifasciatus*, its Indian Ocean sister species. *C. lunulatus* is rare at Christmas Island and forms breeding pairs and mates with the more abundant *C. trifasciatus* to produce hybrids (Hobbs & Salmond 2008; Hobbs *et al.* 2009).

Not only do these new records at Christmas Island represent secondary contact between sister species, but they also represent contact between different colour morphs and genetically distinct clades. For example, we observed the Indian and Pacific Ocean colour morphs of the angelfishes *Pygoplites diacanthus* and *Pomacanthus imperator* together at Christmas Island. Recent genetic analysis have also revealed that widespread Indo-Pacific species are comprised of genetically distinct Indian and Pacific Ocean clades that come into contact at Christmas Island and the Cocos Islands (E. Beck unpublished data). Many widespread coral reef invertebrates also have Indian and Pacific Ocean clades (Benzie 1998), and preliminary investigations indicate that these clades may also come into contact at Christmas Island (Hobbs and Salmond 2008). However, not all Indo-Pacific species have Indian and Pacific Ocean clades (e.g. Horne *et al.* 2008) indicating that the small gaps in the Sunda Shelf Barrier may have allowed gene flow between the Indian and Pacific Oceans for some species. It is also possible that the Sunda Shelf Barrier may have caused species to diverge into Indian and Pacific Ocean clades during periods of low sea levels, however, during periods of higher sea-levels, dispersal between Indian and Pacific Oceans homogenised any genetic structure. Genetic connectivity between Indian and Pacific Ocean clades would have been greatest for species with high dispersal ability that allowed them to cross the large expanse of water west of Indonesia. Even for widespread Indo-Pacific species, Christmas Island may have still provided a stepping-stone that helped maintain genetic connectivity between the Indian and Pacific Oceans.

The biogeographic importance of Christmas Island appears to be similar to the Sunda Islands that lie across Wallace's line in South-East Asia. For terrestrial fauna, the Sunda Islands have facilitated movement of species between two biogeographic regions (Carlquist 1965). However, the Islands have had a filtering effect where movement between the regions is determined by dispersal ability (Carlquist 1965). Christmas Island (and the Cocos Islands) may have had a similar filtering effect on the dispersal of Indian Ocean fishes into the Pacific Ocean and vice versa. Species with high dispersal ability may have dispersed directly between biogeographic regions without the need to colonise Christmas Island. For species with low dispersal ability, Christmas Island may have been too isolated to be an effective stepping-stone and dispersal between regions was not possible. Christmas Island is likely to have been most important for species with moderate dispersal abilities that could not disperse between the Indian and Pacific Ocean without first colonising Christmas Island.

The dispersive larvae stage characteristic of most marine fishes promotes range expansion and additional species are likely to colonise Christmas Island in the future. Whether these colonists establish resident populations will be dependent on the availability of suitable habitat and conspecific mates. The unique biogeographic position of Christmas Island serves as an important stepping-stone in the dispersal of Pacific Ocean species into the Indian Ocean and vice-versa. The biogeographic importance of Christmas Island is likely to vary between marine groups according to the taxa's dispersal ability. The mixing of Indian and Pacific Ocean sister species at Christmas Island has also led to hybridisation, which can have far reaching taxonomic and evolutionary implications.

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