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Review

# Papuan Bird's Head Seascape: Emerging threats and challenges in the global center of marine biodiversity

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ABSTRACT

The Bird's Head Seascape located in eastern Indonesia is the global epicenter of tropical shallow water marine biodiversity with over 600 species of corals and 1,638 species of coral reef fishes. The Seascape also includes critical habitats for globally threatened marine species, including sea turtles and cetaceans. Since 2001, the region has undergone rapid development in fisheries, oil and gas extraction, mining and logging. The expansion of these sectors, combined with illegal activities and poorly planned coastal development, is accelerating deterioration of coastal and marine environments. At the same time, regency governments have expanded their marine protected area networks to cover 3,594,702 ha of islands and coastal waters. Low population numbers, relatively healthy natural resources and a strong tenure system in eastern Indonesia provide an opportunity for government and local communities to collaboratively manage their resources sustainably to ensure long-term food security, while meeting their development aspirations.



## 1. Introduction

Located in the heart of the 'Coral Triangle', the Papuan Bird's Head Seascape (BHS) in eastern Indonesia encompasses over 22.5 million hectares of sea and small islands off the West Papua Province between the latitudes 4°05′S–1°10′N and longitudes 129°14′E–137°47′E (Fig. 1). The BHS has the richest diversity of reef fish and coral species recorded in the world and is regarded by some as the global epicenter of tropical shallow water marine biodiversity (Veron et al., 2009; Allen and Erdmann, 2009, 2012). The Seascape encompasses a diversity of habitats, including the highly enclosed shallow Cendrawasih Bay, to shallow fringing, barrier, patch, lagoon and atoll reefs in Raja Ampat, to mangrove dominated coasts, rivers and inlets in Bintuni Bay. The Seascape also includes critical habitats for globally threatened marine species, including sea turtles and cetaceans.

The boundaries of the BHS were delineated based on biogeographic integrity, oceanic and genetic connectivity between reef areas, shared ecological characteristics and environmental factors that may explain how species are distributed (Green and Mous, 2008). The geographic scale of this review is the Seascape because of its practicality for marine conservation strategies, particularly for the design and implementation of marine protected area (MPA) networks, and its adoption by the six countries of the Coral Triangle – Indonesia, Timor-Leste, Philippines, Malaysia, Papua New Guinea and the Solomon Islands (Coral Triangle Initiative, 2009). The BHS boundaries fall primarily within the West Papua province with only a small portion falling within the adjacent province of Papua. Therefore, BHs boundaries closely align with

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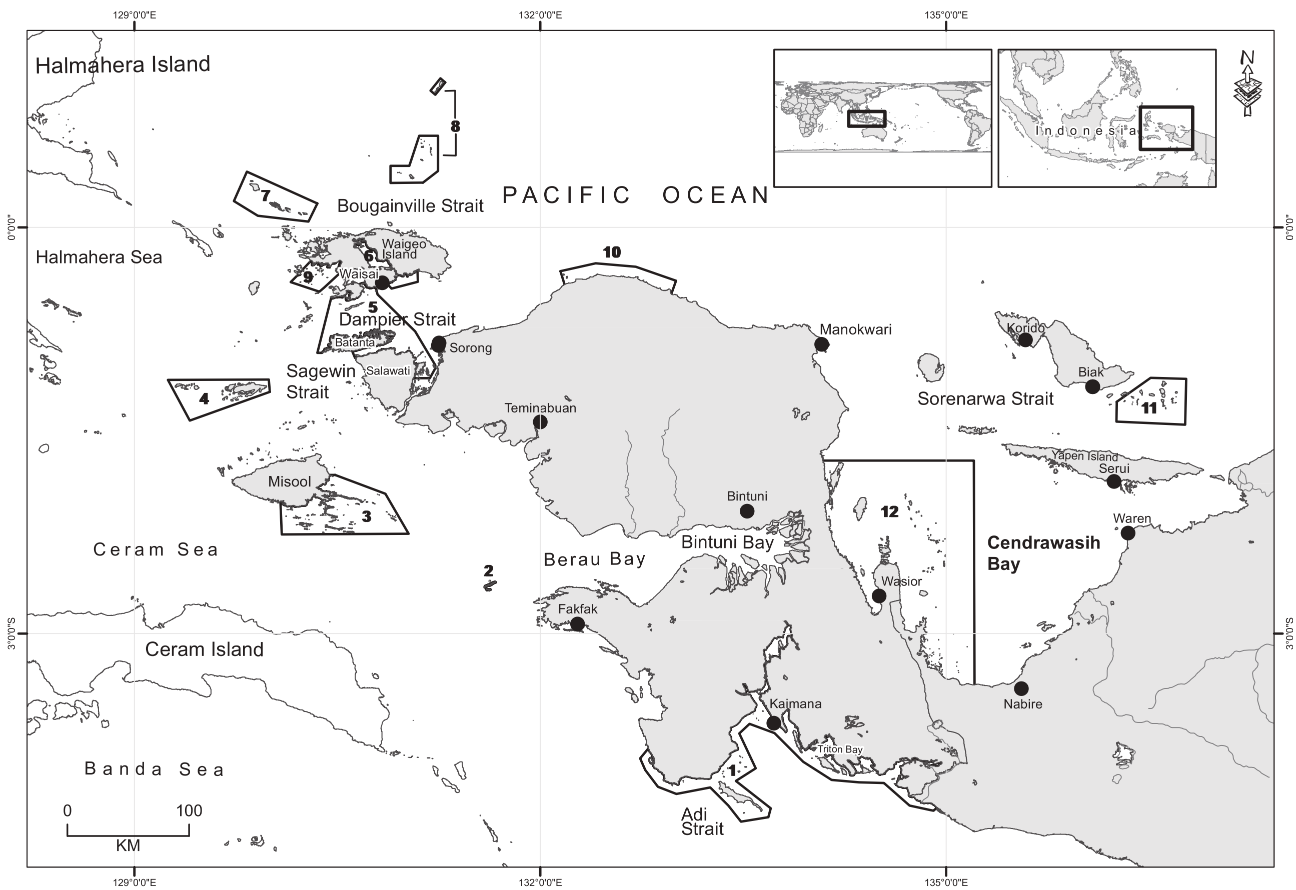


**Fig. 1.** Map of the Bird's Head Seascape showing the location of major towns, islands, and marine protected area (MPA) boundaries. MPAs shown are: 1 = Kaimana, 2 = Sabuda Tataruga, 3 = Southeast Misool, 4 = Kofiau and Boo Islands, 5 = Dampier Strait, 6 = Mayalibit Bay, 7 = Kawe, 8 = Ayau-Asia Islands, 9 = Panjang Islands (previously West Waigeo), 10 = Abun, 11 = Padaido, 12 = Cendrawasih Bay.

governance boundaries in Indonesia. Indonesia currently has a three-tiered system of de-centralized governance, made up of regencies, provinces and a national government. Throughout this paper, the term 'Papua' on its own, is used to represent both the provinces of West Papua and Papua.

Over the last decade, environmental issues in the BHS have received significant attention from local governments and international non-government organizations (NGOs). This interest has been driven by the high diversity of the region and growing concerns over the impacts of rapid escalation in development. Scientists, governments and NGOs have conducted biological, social, economic, and governance studies to support policy, conservation and sustainable development efforts in the region. Much of this work is largely unpublished and available only in the Indonesian language, and therefore inaccessible to the wider science community. This review is the first to synthesize and summarize available data, reports and scientific publications on climate and oceanography, coastal and marine habitats and endangered species in the BHS. It identifies the existing uses, and emerging and increasing threats to the region, and summarizes the governance and policies underpinning natural resource management and conservation efforts in the region.

## 2. Climate and oceanography

### 2.1. Monsoon seasons and rainfall

The equatorial location of the BHS means that the main seasonal influence is monsoons driven by the annual movement of the inter-tropical convergence zone 15° north and south of the equator (Prentice and Hope, 2007). The movement across the equator creates two distinct monsoon seasons. The northwest monsoon extends from November to March and is characterized by warmer SSTs (Fig. 2a), occasional strong winds and ocean swell predominantly in the north. The southeast monsoon from May to October is characterized by cooler sea surface temperatures (SSTs) (Fig. 2b), persistent winds and strong ocean swell in the south. There is a transition period of 1–2 months between seasons characterized by variable and lower winds. Although annual rainfall in Papua averages 2500–4500 mm (Prentice and Hope, 2007), rainfall in coastal cities is lower and averages 100.9–657.2 mm (Fig. 3). Inter-annual variability in rainfall changes significantly with the El Niño Southern Oscillation (ENSO; Prentice and Hope, 2007).

### 2.2. Oceanography

The oceanographic conditions of the BHS are diverse and complex due to the shape of the BHS coastline and its location at the northeastern entrance of the 'Indonesian Throughflow' which transports water from the Pacific to the Indian Ocean (Fig. 4; Vranes and Gordon, 2005). Inter-annual variation in the Indonesian Throughflow is associated with the ENSO and Asian monsoons (Vranes and Gordon, 2005). During the southeast monsoon, the South Equatorial Current (SEC) travels west across the northern coast of the BHS, merging with the Halmahera Eddy and joining the Northern Equatorial Counter Current (NECC) flowing east. The SEC reverses direction during the northwest monsoon (Fig. 4). Temperature, salinity and chemical tracer data suggest that

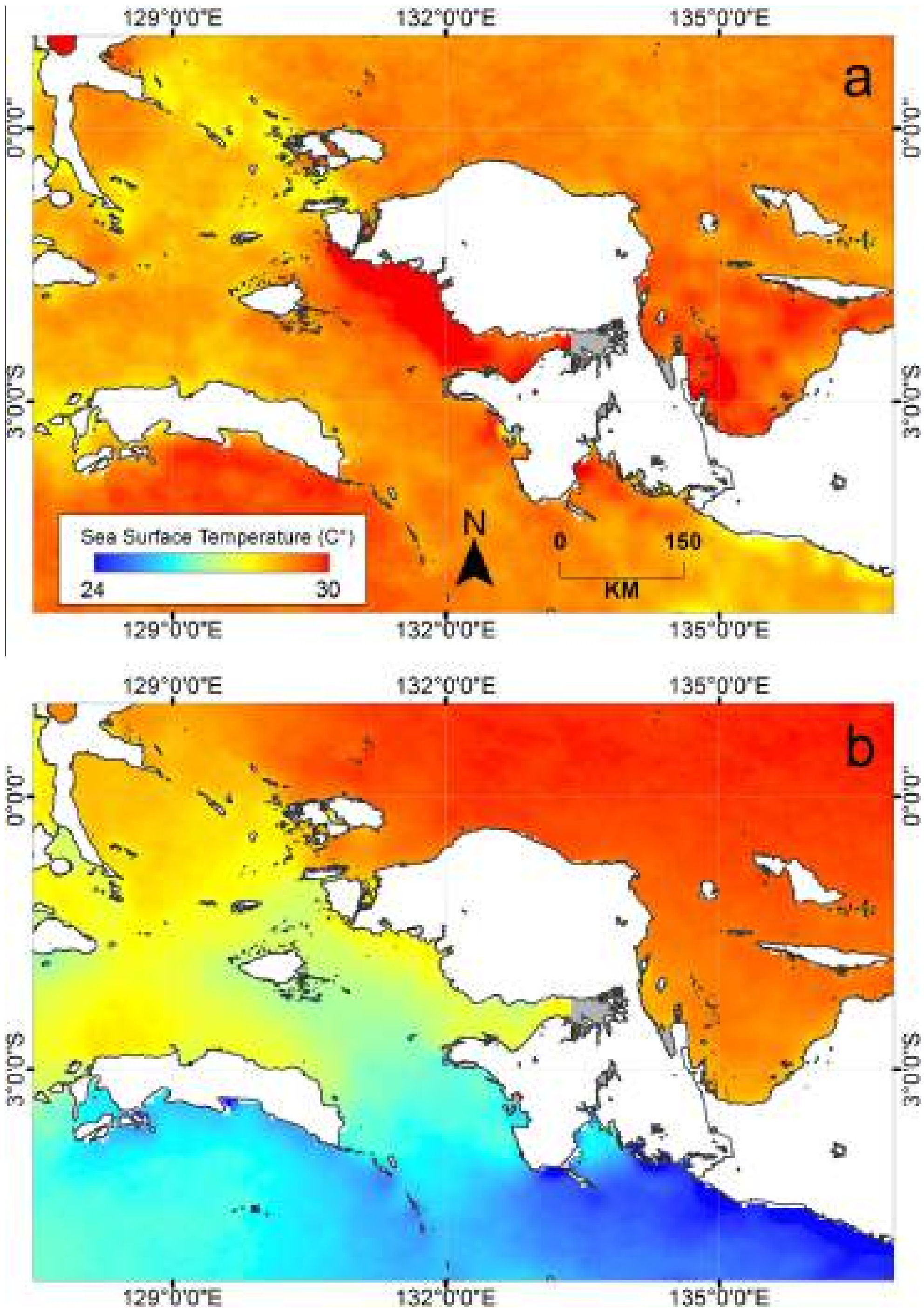


**Fig. 2.** Broad scale seasonal sea surface temperature (SST) patterns in the Bird's Head Seascape. SST data at 4 km-weekly resolution (Heron et al., 2010), based upon Pathfinder Version 5.0 SST data (Kilpatrick et al., 2001), were averaged to produce seasonal mean temperatures (a) November to March; and (b) May to October for the period 1985–2009. Data deep within enclosed bays were masked in the images (gray color) due to the reduced confidence in gapfilled data quality, related to extended cloud periods regularly experienced in the region (particularly during November to March).

some of the SEC flows south past Raja Ampat into the Ceram and Halmahera Seas (Gordon and Fine, 1996). Some waters however move between the Raja Ampat islands where complex coastlines, deep channels and strong tidal currents create local eddies and turbulence (Gordon and Fine, 1996; DeVantier et al., 2009) and likely promote good larval connectivity among reefs (Crandall et al., 2008; DeBoer et al., 2008). In contrast to these strong and complex currents, Cendrawasih Bay is relatively enclosed with limited exchange with the SEC, which likely promotes larval retention (Crandall et al., 2008; DeBoer et al., 2008).

### 2.3. Temperature and salinity patterns

Ninety-eight *in situ* temperature loggers (HOBO ProV2) installed in the BHS across a wide range of coral reef habitats showed marked geographic and seasonal differences in SSTs (Fig. 5). The

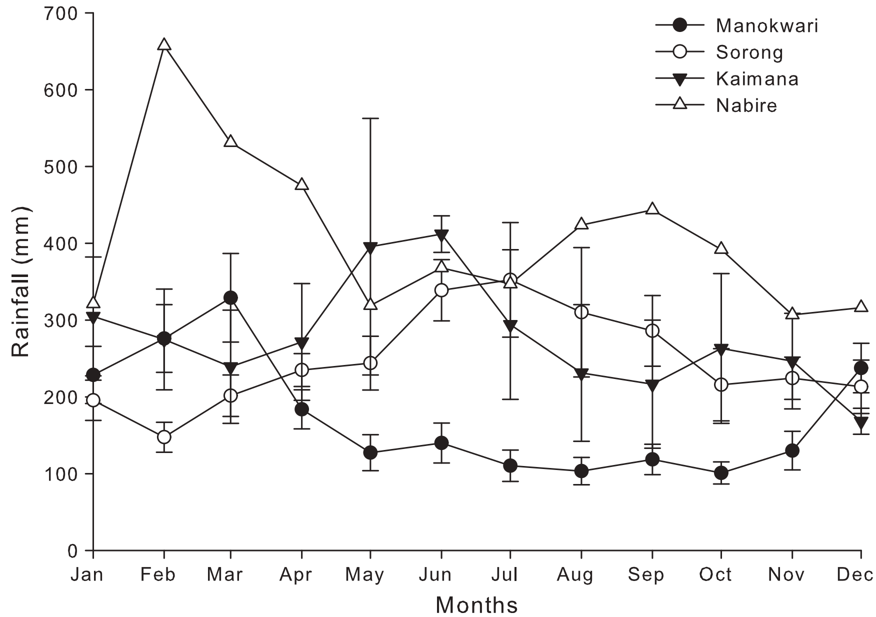


**Fig. 3.** Average monthly rainfall patterns recorded at Manokwari (2000–2010), Sorong (2000–2010) Kaimana (2008, 2010–2011) and Nabire (2009–2010). Error bars are standard error. Source: Badan Meteorologi Klimatologi dan Geofisika.

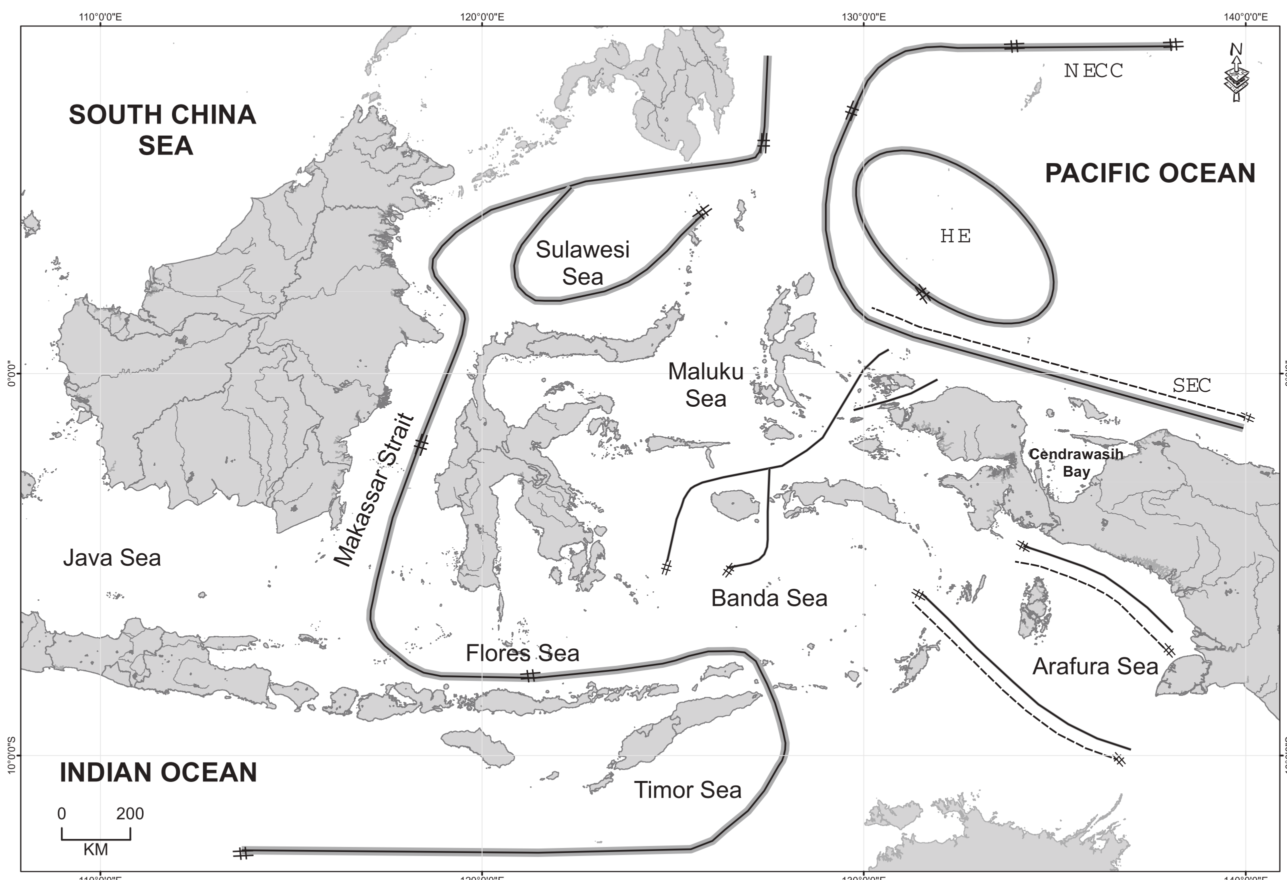


**Fig. 4.** Main oceanographic currents during the northwest and southeast monsoons in Eastern Indonesia. Dotted arrows indicate reverse flow of currents during the southeast monsoon. Source: Atlas Sumberdaya Kelautan, Bakosurtanal, 2006.

average SST in Raja Ampat was 29.0 °C, with temperatures ranging from 19.3 to 36.0 °C (Fig. 5a and b). Several important areas of cold-water upwelling have been identified at Southeast Misool, Dampier Strait, Sagewin Strait, and the Bougainville Strait in northwest Raja Ampat. These cold upwellings are present all year, but are most intense during the southeast monsoon when strong winds from the south help drive this upwelling (Figs. 2 and 5c and d). Geological features such as karst limestone channels and la-

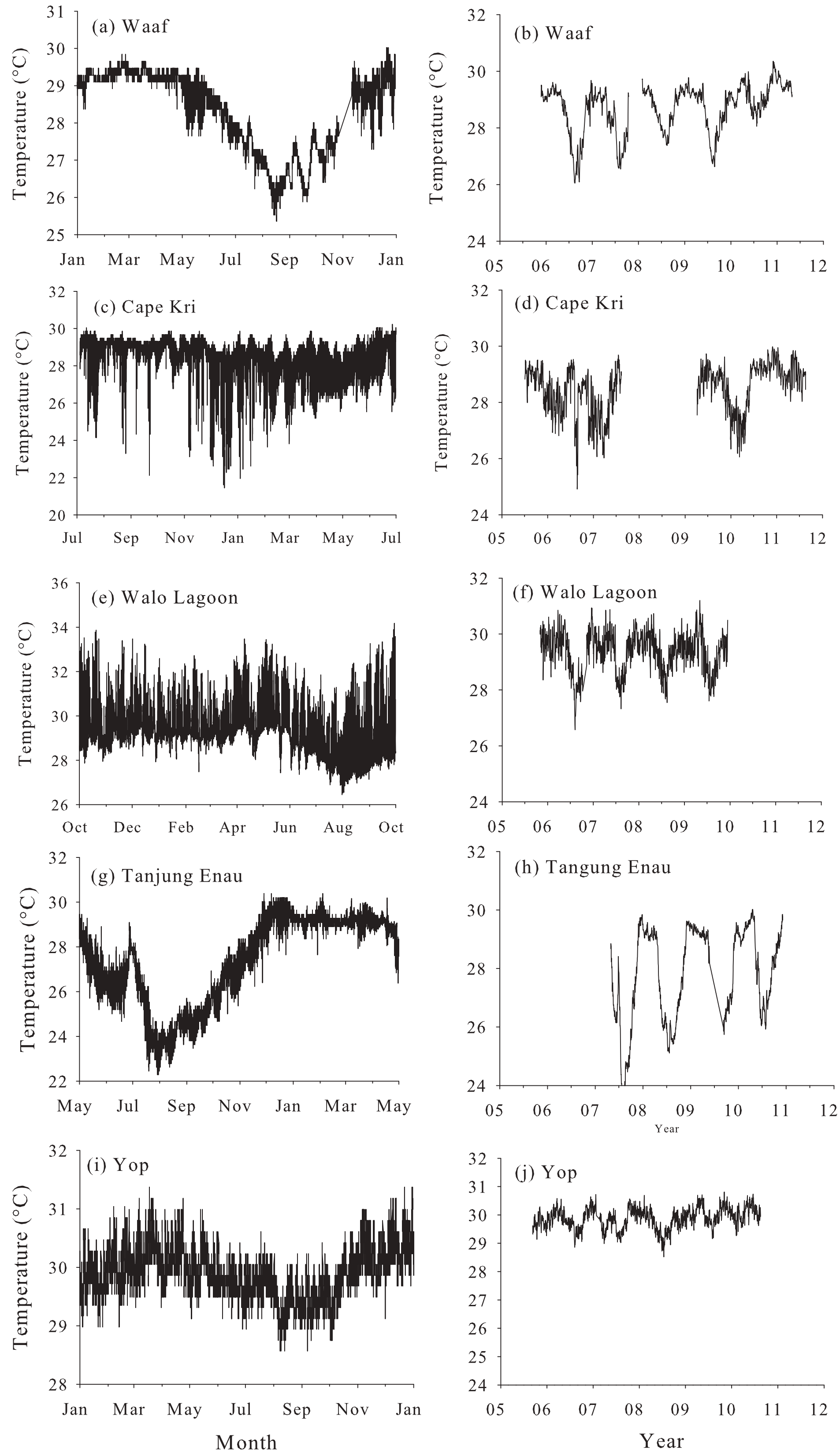


**Fig. 5.** *In situ* sea surface temperature (SST) patterns in the Bird's Head Seascape. (a and b) Waaf Island (3 m) in Southeast Misool represents the main SST patterns found in Raja Ampat. (c and d) Cape Kri (40 m) in Raja Ampat represents a reef with frequent upwellings. (e and f) Walo Lagoon (1 m) in Kofiau and Boo Islands MPA represents shallow lagoon reefs exposed to high daily fluctuations in SST. (g and h) Tangjung Enau (20 m) represents the main SST pattern in Kaimana. (i and j) Yop Island (3 m) represents the main SST pattern in Cendrawasih Bay. The graphs on the left show SSTs recorded every 15 min over a 13-month period. The graphs on the right represent mean daily SSTs recorded between 2005 and 2012 at each of the sites, for which data are available.

goons in some parts of Raja Ampat highly restrict water circulation where dramatic heating occurs during the day and cooling at night (Fig. 5e and f). Mayalibit Bay experiences temperatures ranging from 28.0 to 34.1 °C, and intertidal reef flats in Raja Ampat are also exposed to wide temperature swings of 7–8 °C on a daily basis.

The Kaimana region is on average significantly cooler than Raja Ampat (average temperature of 28.1 °C), with a recorded range of 22.3–30.9 °C (Fig. 5g and h). This southern region showed a strong seasonality of SST fluctuations, with cold-water upwellings prominent during the southeast monsoon period (Fig. 2). These cold upwellings coincide with increased chlorophyll-a and primary productivity in Kaimana's coastal and marine waters and further south to the Arafura Sea (see Fig. 3b in Gordon, 2005). Biak, Manokwari and Cendrawasih Bay showed a much less variable temperature regime in the eastern BHS, with SSTs staying between 29.4 and 30.0 °C for most of the year (Fig. 5i and j).

## 3. Coastal and marine habitats and ecosystems

### *3.1. Mangrove forests*

Coastal areas and islands in the BHS have a range of forest types – sago, palm and mixed swamps, mangrove wetlands, sub-montane and primary lowland rain forests. Papua contains the world's most extensive and diverse mangrove communities (Alongi, 2007; Spalding et al., 2010) and more than half of Indonesia's 40,000 $km^2$ of mangroves. Many of these mangrove stands are still in good condition, although increasing development and mining are now significant threats (Alongi, 2007). Mangrove forests are a valuable source of firewood, timber and traditional medicines for local Papuan communities. Within the BHS, 35 species of mangrove have been recorded (Huffard et al., 2009). The region's most extensive mangrove forest (450,000 ha) that contains old growth mangrove stands, occurs in Bintuni Bay (Alongi, 2007; Gandi et al., 2008), part of which is designated as a National Nature Reserve. Other significant mangrove stands occur on the eastern coast of Cendrawasih Bay and the western coastline of the Bird's Head around Kaimana (Alongi, 2007). In Raja Ampat, mangroves are considered sparse compared to mainland communities, although these are quite diverse with 25 species recorded from fringing and estuarine mangrove communities (Firman and Azhar, 2006). The fauna of Papuan mangroves is poorly known and there are little data on the current status of mangrove forests throughout the BHS.

### *3.2. Seagrass beds*

The BHS lies in the center of biodiversity for seagrass (Short et al., 2007), with 11 species reported by McKenzie et al. (2007). Little is known about the distribution, ecology or condition of seagrass beds in this region. Seagrass occurs in four main habitat types – estuarine, coastal, reef flats and deep water. Deep water seagrasses are the least understood but nonetheless ecologically important; they are generally dominated by *Halophila*, the main genus eaten by dugongs (McKenzie et al., 2007). Cendrawasih Bay has extensive lagoonal seagrass beds in the southwestern area of the Bay which were reported to support dugongs (Petocz, 1989). In Raja Ampat,


**Fig. 6.** Photographs of coral reef habitats in marine protected areas in the Bird's Head Seascape. Photograph credits in parentheses. (a) Aerial view of Walo lagoon in Kofiau (M. Ammer/Papua Diving), (b) shallow karst fringing reefs in Panah-Panah Strait in Southeast Misool at low tide (S. Mangubhai/TNC), (c) aerial view of large oceanic atoll in Ayau (C. Huffard/CI), (d) extensive karst "beehive" lagoon with fringing reefs in Wayag Island of Kawe (M.V. Erdmann/CI), (e) *Tubastrea* and soft coral dominated reefs in Triton Bay in Kaimana (Shimlock-Jones/Secret Seas), and (f) *Acropora*-dominated patch reefs in Cendrawasih Bay (Shimlock-Jones/Secret Seas).

the islands of Sayang, Kawe, Waigeo, Batanta and Salawati, as well as several smaller islands support seagrass beds that are important foraging sites for green turtles and habitat for rabbitfish (Siganidae), an important subsistence and small scale commercial fishery for local communities (Firman and Azhar, 2006; McKenzie et al., 2007). In the eastern BHS, extensive seagrass beds are found around Biak, Padaido and Yapen Islands, while in the south beds are found in Arguni, Kayumerah and Etna Bays near Kaimana. The most significant threats to seagrass in the BHS are deforestation and coastal development causing increased turbidity and sedimentation from runoff, as well as reclamation of shallow coastal habitats that smothers seagrass beds.

### 3.3. Coral reefs

The BHS boasts the highest diversity of corals, reef fishes and stomatopods in the world (Veron et al., 2009; Huffard et al., 2009; Allen and Erdmann, 2009, 2012). Surveys have recorded over 577 described species of scleractinian corals (75% of the world's total), with individual reefs hosting up to 280 species per hectare (Veron et al., 2009; Wallace et al., 2011). An additional 25–40 undescribed coral species have also been collected, such that the total scleractinian diversity in the BHS is expected to exceed 600 species once taxonomic work is completed on these collections (L. DeVantier and E. Turak, personal communication). Within the BHS the highest diversity of corals has been recorded in Raja Ampat, with 553 known species (Veron et al., 2009). Two rapid ecological assessments conducted in 2001 and 2002 in Raja Ampat also recorded 41 of the 90 Alcyonacean (soft coral) genera and 699 mollusc species (McKenna et al., 2002; Donnelly et al., 2003), while more recent studies have documented 57 reef-associated stomatopod species in the BHS, four of which are considered endemic to the region (Huffard et al., 2009). Corals have been found to 160m depth in Raja Ampat, though those beyond

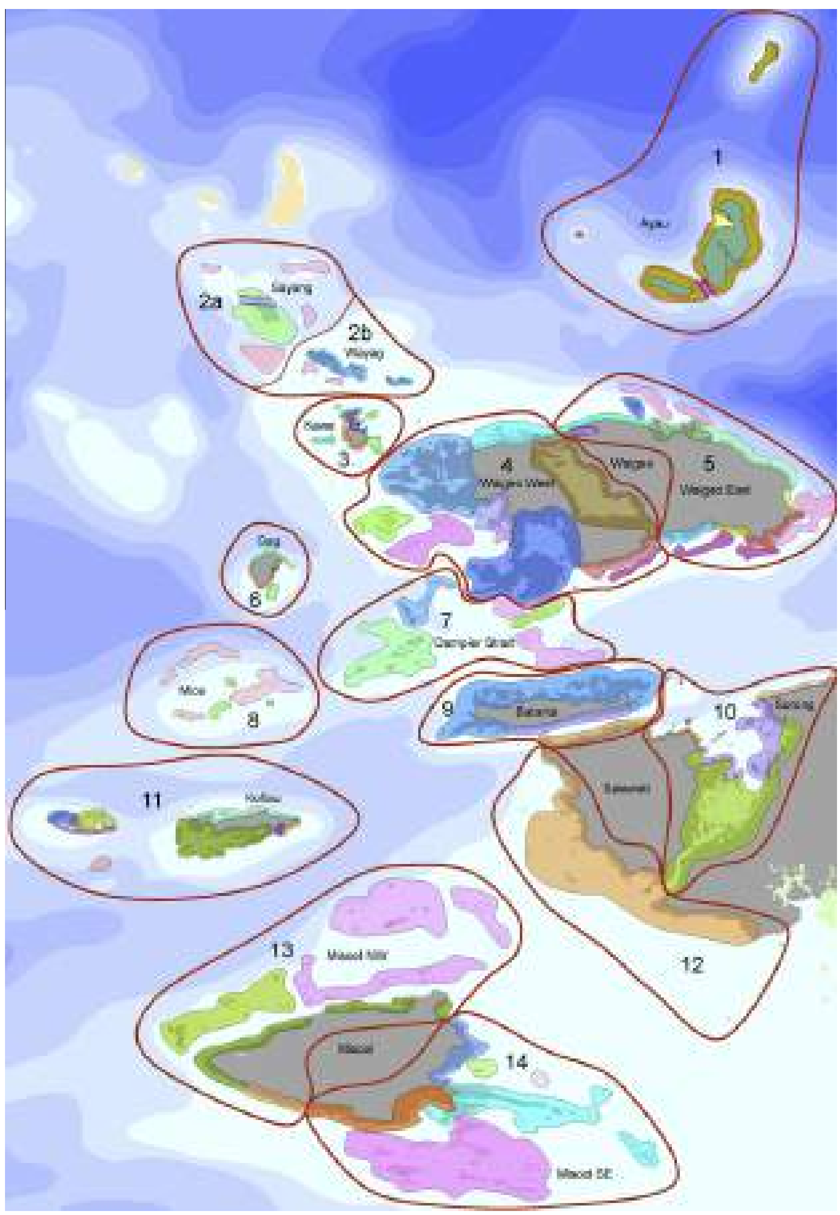


**Fig. 7.** Coral reef classification for Raja Ampat showing 14 reefscapes (100–1000s km scale) and 75 habitats (10–100s km scale). 1 = Ayau (5), 2 = Wayag (3), 3 = Kawe (5), 4 = West Waigeo (10), 5 = East Waigeo (11), 6 = Gag (4), 7 = Dampier Strait (5), 8 = Mios (2), 9 = Batanta (3), 10 = Sorong (4), 11 = Kofiau (9), 12 = Salawati (1), 13 = Northwest Misool (4), 14 = Southeast Misool (6). Source: DeVantier et al. (2009). The number of habitats found in each reefscape are provided in parentheses. Habitat descriptions are provided in supplementary information.

**Table 1**
Benthic cover (mean ± standard deviation) in marine protected areas (MPAs) the Bird's Head Seascape. No data are available for reefs outside of MPAs. Only the most recent data is presented here (year). PIT = point intercept transect (Wilson and Green, 2009), MT = manta towing (English et al., 1997). PIT surveys were done at 8–10 m depth at all sites. *N* = number of sites sampled, where applicable. '–' means no data collected.

| MPAs | Methods | Year | *N* | Habitat (PIT only) | Hard coral | Soft coral | Coralline algae | Macro algae | Rock substrate | Rubble | Sand | Data source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Kaimana | MT | 2010 | – | | 15.2 ± 14.2 | – | – | – | 16.4 ± 14.0[a] | 9.9 ± 10.0 | 41.4 ± 29.1 | CI |
| South east Misool | PIT | 2011 | 32 | Fringing reefs, semi-exposed/semi-sheltered reefs | 40.9 ± 12.5 | 11.2 ± 9.2 | 5.0 ± 3.8 | 4.7 ± 5.8 | 16.2 ± 6.2 | 12.4 ± 10.7 | 2.9 ± 4.2 | TNC |
| | PIT | 2009 | 37 | | 44.4 ± 16.2 | 10.5 ± 10.5 | 7.1 ± 5.8 | 8.8 ± 10.1 | 9.3 ± 7.7 | 11.8 ± 10.2 | 2.0 ± 5.3 | |
| | MT | 2008 | – | | 16.1 ± 10.2 | 13.2 ± 9.9 | – | 3.7 ± 7.8 | 34.0 ± 30.9 | 17.4 ± 12.8 | 13.9 ± 12.4 | |
| Kofiau and Boo Islands | PIT | 2011 | 25 | Fringing reefs, exposed and semi-exposed | 30.8 ± 10.4 | 12.1 ± 7.4 | 2.5 ± 2.3 | 4.2 ± 5.1 | 14.0 ± 6.4 | 13.7 ± 9.8 | 14.7 ± 10.2 | TNC |
| | PIT | 2010 | 30 | | 28.5 ± 15.5 | 8.2 ± 7.2 | 11.1 ± 9.9 | 4.0 ± 5.4 | 3.5 ± 4.1 | 16.5 ± 15.6 | 14.5 ± 11.5 | |
| | PIT | 2009 | 31 | | 36.0 ± 14.7 | 14.8 ± 9.6 | 0.0 ± 0.0 | 3.9 ± 5.2 | 9.2 ± 7.2 | 18.7 ± 11.8 | 8.8 ± 9.1 | |
| | MT | 2008 | – | | 26.7 ± 17.5 | 14.8 ± 10.1 | – | 4.2 ± 5.3 | 17.6 ± 18.8 | 10.5 ± 9.4 | 26.2 ± 24.3 | |
| Dampier Strait[b] | PIT | 2011 | 21 | Fringing and patch reefs, exposed, and semi-exposed | 24.4 ± 16.0 | 15.8 ± 18.5 | 0.5 ± 1.4 | 1.7 ± 4.5 | 9.4 ± 13.4 | 11.8 ± 14.6 | 30.7 ± 26.3 | CI |
| | PIT | 2010 | 33 | | 23.2 ± 13.8 | 9.3 ± 13.8 | 0.7 ± 1.4 | 1.4 ± 2.9 | 8.4 ± 14.0 | 17.6 ± 14.6 | 11.2 ± 12.1 | |
| | MT | 2010 | – | | 27.4 ± 15.6 | – | – | – | 14.3 ± 9.5[a] | 18.0 ± 10.7 | 22.0 ± 17.2 | |
| | MT | 2008 | – | | 24.9 ± 12.0 | – | – | – | 21.0 ± 13.9[a] | 18.9 ± 14.2 | 12.1 ± 13.9 | |
| Mayalibit Bay[b] | PIT | 2010 | 8 | Fringing barrier and patch reefs, exposed, semi-exposed, and sheltered | 17.4 ± 14.8 | 13.4 ± 11.8 | 1.4 ± 2.5 | 7.3 ± 12.5 | 9.3 ± 10.6 | 17.7 ± 22.2 | 24.0 ± 23.3 | CI |
| | MT | 2010 | – | | 21.9 ± 15.9 | – | – | – | 19.2 ± 12.0[a] | 11.4 ± 10.1 | 22.8 ± 23.8 | |
| | MT | 2008 | – | | 18.8 ± 13.2 | – | – | – | 21.8 ± 15.6[a] | 9.5 ± 10.4 | 26.8 ± 23.6 | |
| Kawe | PIT | 2010 | 18 | Fringing reefs, exposed and semi-exposed | 30.2 ± 20.1 | 15.0 ± 16.7 | 0.6 ± 2.0 | 9.0 ± 14.7 | 17.4 ± 18.9 | 12.1 ± 14.8 | 14.8 ± 20.1 | CI |
| | MT | 2008 | – | | 20.6 ± 16.7 | – | – | – | 40.9 ± 22.8[a] | 8.8 ± 11.9 | 12.2 ± 15.8 | |
| Raja Ampat archipelago | PIT | 2011 | 14 | Fringing and reefs, exposed and semi-exposed | 29.3 ± 13.0 | 9.0 ± 7.4 | 1.6 ± 3.9 | 0.6 ± 1.4 | 6.6 ± 5.3 | 24.0 ± 17.8 | 25.2 ± 13.9 | CI |
| (Southwest Waigeo) | MT | 2011 | | | 25.2 ± 14.6 | – | – | – | 15.7 ± 7.8[a] | 19.9 ± 9.9 | 25.7 ± 15.0 | |
| Ayau-Asia[b] | PIT | 2010 | 20 | Atoll fringing reefs, exposed | 38.1 ± 18.1 | 12.6 ± 13.5 | 0.9 ± 1.9 | 5.2 ± 8.0 | 23.5 ± 15.9 | 23.3 ± 15.9 | 4.8 ± 9.2 | CI |
| | PIT | 2009 | 10 | | 14.3 ± 7.2 | 5.4 ± 6.4 | 0.0 ± 0.0 | 4.6 ± 5.8 | 14.7 ± 8.2 | 14.7 ± 8.2 | 3.5 ± 6.1 | |
| | MT | 2007 | – | | 33.6 ± 15.8 | – | – | – | 33.4 ± 17.2[a] | 33.4 ± 17.2 | 5.3 ± 8.3 | |
| Cendrawasih Bay | PIT | 2011 | 29 | Fringing reefs, exposed, semi-exposed and sheltered | 40.5 ± 12.5 | 2.5 ± 4.6 | 0.2 ± 0.7 | 0.6 ± 1.9 | 3.4 ± 4.0 | 19.2 ± 9.8 | 16.1 ± 12.9 | WWF |
| | PIT | 2010 | 15 | | 38.3 ± 14.4 | 4.3 ± 5.6 | 0.9 ± 1.9 | 2.8 ± 3.5 | 10.5 ± 5.9 | 19.9 ± 11.7 | 10.1 ± 13.0 | |

[a] For CI data collected through manta tows, dead coral was placed under 'rock substrate' in the table.
[b] Yearly surveys do not represent repeat measures of the same sites. Different sectors of the MPAs were measured in different years.

the reaches of SCUBA remain uncharacterized (B. Robison, unpublished data).

Similarly, intensive survey work around the BHS over the last decade has recorded 1638 species of coral reef fishes comprising 476 genera and 117 families (Allen and Erdmann, 2009, 2012). Within the BHS, the highest diversities have been recorded in Raja Ampat (1437 spp.), the Fakfak-Kaimana coast (1005 spp.) and Cendrawasih Bay (965 spp.). Allen and Erdmann (2009) reported a total of 26 endemic reef fish species (from 14 families) in the BHS, though more recent surveys have now increased this total to 41 (Dimara et al., 2010; Allen and Erdmann, 2012). The factors that contribute to local endemism are thought to be in part associated with the geological history of the region. For example, there is evidence that Cendrawasih Bay was isolated for a substantial period over the past 5 million years, resulting in high local endemism (11 endemic reef fishes and 18 endemic reef-building corals currently recognized), and significant genetic divergence of many marine invertebrate populations in the Bay (DeBoer et al., 2008; Crandall et al., 2008; Wallace et al., 2011; Allen and Erdmann, 2012).

The main reef types found in the region are fringing and patch reefs, and to a lesser extent seamounts, atolls and barrier reefs (Fig. 6; McKenna et al., 2002; WWF, 2003; Donnelly et al., 2003;). In Raja Ampat, published and unpublished information and expert opinion on oceanography, bathymetry and physico-chemical parameters, habitats and distributions of coral communities and reef fishes were used to develop a more detailed reef classification comprising 14 broad scale reef types termed ‘reefscapes’ (scale of 100–1000s km) and 75 reef habitats (scale of 10–100s km) (Fig. 7, Supplementary materials, DeVantier et al., 2009). Reef endemism is high, with 5–6% of all coral species and 2.5% of reef fish found only in this region (Allen and Erdmann, 2012).

Unlike many other parts of Indonesia and wider Southeast Asia (Burke et al., 2011), the coral reefs in the BHS are in a relatively healthy state. Reef health monitoring in 9 of the 12 BHS MPAs using point intercept transect methods (Wilson and Green, 2009) showed average live hard coral cover ranged from 14.3% to 44.4% across all the MPAs (Table 1). Manta towing (English et al., 1997) covering a much wider area of the MPAs recorded average coral cover ranging from 15.2% to 33.6 across all the MPAs (Table 1).

The main threats to coral reefs are from destructive fishing such as bomb, cyanide and compressor fishing, though this does not occur to the same intensity or geographic spread as other parts of Indonesia, and is mainly done by outside fishers frequenting the area (McKenna et al., 2002; Ainsworth et al., 2008). There is no documentation of major widespread crown-of-thorns starfish (*Acanthaster planci*) outbreaks on reefs in the BHS. Damaged reefs in the BHS MPAs (based on percentage of rubble), ranged from 11.8% to 24.0% and 8.8% to 33.4% in point intercept transect and manta towing surveys, respectively (Table 1). Formal patrols with enforcement agencies and informal patrols with local communities have been largely effective in reducing and in some case stopping destructive fishing in MPAs (TNC and CI, unpublished data). However, overfishing continues and is largely uncontrolled (see Section 5.2 for details) and poses a significant and growing threat to coral reefs.

### 3.4. Marine lakes

Marine lakes are land-locked water bodies that have a marine character maintained by tidal fluctuations pushing seawater through subterranean crevices or porous karst (Becking et al., 2009). At least 45 marine lakes have been identified in Raja Ampat, with the highest numbers occurring in Kawe and Southeast Misool MPAs (Becking et al., 2009, 2011). These lakes vary in biophysical parameters such as bathymetry, size, coastline, salinity, water temperature, pH and degree of connection to the sea, which results in a variety of biotic assemblages (Fig. 8; Becking et al., 2011). Fauna observed in Raja Ampat’s lakes include corals, nudibranchs, shrimps, fish, bivalves, sponges (including a number of endemic species), ascidians, ctenophores, and jellyfish including *Cassiopeia*, *Mastigias* and *Aurelia* spp. (Becking et al., 2009). With the exception of six, all lakes in Raja Ampat are in a pristine state with little threats from invasive species or tourism activities (Becking et al., 2009, 2011). The majority of lakes in Raja Ampat do not have stingless jellyfish and are difficult to access safely, which may focus tourism and any impacts from tourism on just a few marine lakes (Becking et al., 2009).

### 3.5. Soft sediment communities

Soft sediment communities are well represented but poorly understood in the BHS. Rodoliths, soft corals and sponges provide low-rugosity shelter covering up to 75% of substrata in some areas. Both black and white sand habitats exist in sheltered bays, coves and barrier habitats along Raja Ampat, the Wasior peninsula (particularly the eastern coast) in Cendrawasih Bay, Bintuni Bay and the greater Fakfak-Kaimana coast, especially Arguni, Etna and Triton Bays. Preliminary ROV surveys of deeper waters (100–865 m) soft-sediment communities revealed a wide range of species including deep-sea frogfish, Oegopsid squid, chaetognaths and siphonophores (B. Robison, personal communication).

## 4. Threatened and protected species

### 4.1. Turtles

Major nesting beaches for green (*Chelonia mydas*), hawksbill (*Eretmochelys imbricata*), olive ridley (*Lepidochelys olivacea*) and leatherback (*Dermochelys coriacea*) turtles are found on the coasts and small islands of the BHS. Among these are Indo-Pacific region-

**Fig. 8.** Marine lake in limestone karst in Raja Ampat (left photo, Muhajir/TNC). Stingless jellyfish (*Mastigias* sp.) found in marine lakes (right photo, C. Huffard/CI).

ally significant nesting beaches for leatherback and olive ridley turtles at Jamursba-Medi and Wermon in Abun MPA; green turtles at Piai and Sayang Islands in Kawe MPA, Pisang Island in the Sabuda Tataruga MPA and Venu Island in the Kaimana MPA; and hawksbill turtles at Venu Island (WWF and Yayasan Penyu Papua, unpublished data; see also Tapilatu and Tiwari, 2007; Hitipeuw et al., 2007; Benson et al., 2007, 2011).

The many threats faced by turtles in the BHS include habitat destruction of nesting beaches from coastal development, beach erosion, pollution, egg predation, poaching of adults and eggs, bycatch (Hitipeuw et al., 2007; Tapilatu and Tiwari, 2007) and saltwater inundation as a result of increasing occurrence of storm surges during extreme high tides (M.V. Erdmann, personal observations). Hitipeuw et al. (2007) estimated a fourfold decline in the number of nesting leatherbacks from 1985 (1000–3000 females/annum) to 2004 (300–900 females/annum), with this pattern of decline continuing to 2011 (Fig. 9).

Post-nesting migration patterns of leatherback turtles from Jamursba-Medi across 4800 to 21,000 km of ocean to Philippines, Malaysia, South China Sea, Sea of Japan, the equatorial Pacific and North America are well documented (Benson et al., 2007, 2011). Satellite telemetry showed some of the summer nesting leatherback turtles traveled 170–315 km west to Raja Ampat during inter-nesting periods, while some of the winter nesters traveled 120–300 km east to Cendrawasih Bay (Benson et al., 2011). Although no quantitative estimates are available, locals report high bycatch rates during nesting seasons (Hitipeuw et al., 2007). The movement patterns of turtles in the BHS indicated that foraging grounds may be more than 100 km from the nesting sites, and requires a trans-boundary approach both within and outside Indonesia to protecting these regionally significant populations.

### 4.2. Sharks

With no gear restrictions or catch limits, sharks have been systematically harvested since the 1980s from Raja Ampat, Kaimana and other parts of the BHS mainly for their high-valued fins, often without licenses and mostly by outsiders from Buton, Seram, Suluwesi and Halmahera (Varkey et al., 2010). The price of shark fins has increased more than ten-fold between 2002 and 2012 from USD$5–8/kg to USD $82–118/kg (McKenna et al., 2002; J. Fudge, personal communication), providing a strong incentive for overharvesting.

Underwater visual census (UVC) data from the last 2 to 3 years in 6 MPAs in Raja Ampat showed there are very few reef sharks present in the regency. For example, only 6 sharks in Kofiau and Boo Islands MPA were recorded during 26 days of UVC surveys in 2011 (TNC, unpublished data). While these numbers are very low compared to other tropical reefs, there are signs of recovery with an increased number of black-tip sharks (*Carcharhinus melanopterus*) sighted by communities patrolling no-take zones in Kawe and Southeast Misool MPAs and recorded in UVC surveys (CI and TNC, unpublished data). The Raja Ampat government is preparing a local law that will ban shark harvesting in its regency waters, which if passed, will be the first large-scale shark ban for Indonesia.

Despite the widespread depletion of reef sharks, the BHS still maintains healthy populations of several shark species that are not targeted for their fins, including tasseled wobbegongs (*Eucrossorhinus dasypogon*) and the three species of epaulette or "walking" sharks (*Hemiscyllium freycineti*, *Hemiscyllium galei*, and *Hemiscyllium henryi*) considered endemic to the BHS (Allen and Erdmann, 2008). There are also consistent sightings of whale

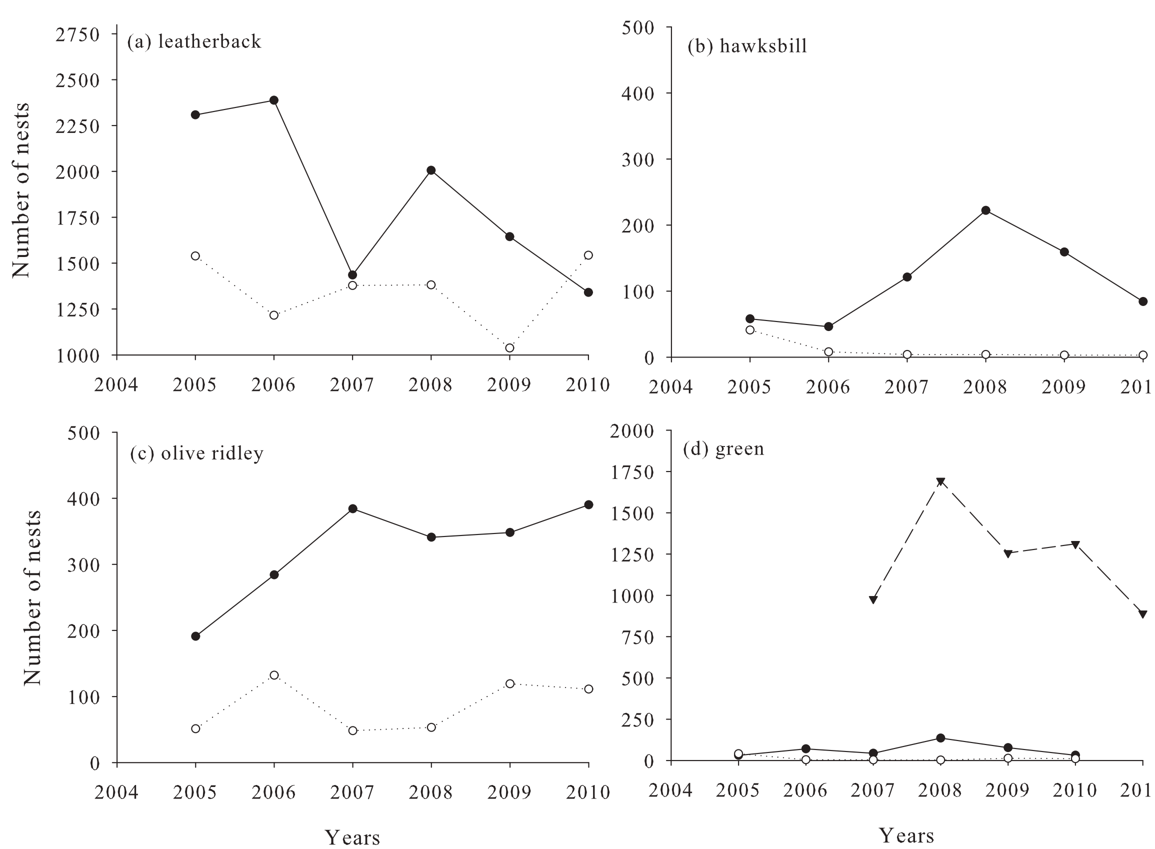


**Fig. 9.** Annual trends in turtle nesting populations at Jamursba-Medi (black circles), Wermon (white circles) and Piai Island (black triangles) in the Bird's Head Seascape. Data are collected each morning at each of these sites by locally trained monitoring officers.

sharks (*Rhincodon typus*) in Cendrawasih Bay and Kaimana, often associated with lift net ('*bagan*') fisheries that target anchovy aggregations. While whale sharks are sighted year round in Cendrawasih Bay, it is not known if these represent a resident or migratory population. In 2011, up to 26 whale sharks (ca. 8–10 m in length) at a time were sighted in Nabire regency in Cendrawasih (C. Hitipeuw, personal observations), and 16 individuals were observed in the Iris Strait in Kaimana (D. Pada, personal observations). The observed annual increase in the number of lift net fishers operating in the BHS may impact upon these whale shark populations through over-harvesting of their anchovy prey.

### 4.3. Whales and dolphins

Although there are few published studies of cetaceans in the BHS, short term surveys and long term incidental observations indicate that this region is a cetacean 'hotspot' and supports diverse and healthy populations for numerous species on the IUCN Red List. Of the 31 cetacean species recorded in Indonesian waters (Tomascik et al., 1997; Rudolf et al., 1997), 15 have been recorded in the BHS including Bryde's, false killer, killer and sperm whales, and Indo Pacific humpback, pan tropical spotted and Fraser's dolphins (Rudolf et al., 1997; Kahn, 2007, 2009). Migratory species such as baleen and sperm whales are sighted annually in Dampier and Sagewin Straits in Raja Ampat (Wilson et al., 2010a, TNC/CI, unpublished data). Frequent year-round sightings of Bryde's whales from Raja Ampat south to Bintuni Bay (Kahn et al., 2006) and Triton Bay suggest resident populations (Kahn, 2009). This high species diversity reflects the diversity and proximity of coastal and oceanic habitats including seamounts and canyons – a consequence of the narrow continental shelves in this region (Kahn, 2007).

Although cetaceans are protected from harvest in Indonesian waters, they face increasing threats and stressors from ship strikes, entanglement in fishing nets, loss of coastal habitats and plastic pollution. One emerging threat to cetaceans in BHS is from undersea mining and seismic testing. Extensive seismic testing occurred in Raja Ampat and Cendrawasih Bay in 2010 with numerous mining leases already granted over areas identified as migratory corridors or feeding grounds for cetaceans. Seismic surveys are known to disrupt cetaceans and their natural migration and feeding patterns, and the animals can become displaced and may show avoidance or stress behavior estimated up to 7–12 km from a large seismic source (McCauley et al., 2000).

### 4.4. Dugongs

Dugongs have been recorded in coastal areas throughout the BHS including Cendrawasih Bay, Biak and Padaido Islands, Kwatisore Bay, Sorong, Raja Ampat, Bintuni Bayand the Fakfak-Kaimana coast (Marsh et al., 2002; De Iongh et al., 2009; Kahn, 2009). In Raja Ampat, aerial surveys have shown that dugongs are widely distributed around the main islands with sightings commonly reported around Salawati and Batanta Islands, east Waigeo Island, Dampier Strait (particularly in southern Gam Island) and northern Misool, including offshore (Wilson et al., 2010a). Numerous sightings of both individuals and family groups of dugongs (5–10 animals) were recorded in eastern Waigeo, Batanta and western Salawati Islands (Wilson et al., 2010a) and should be a focus for conservation efforts. These sightings have increased the reported range of dugongs in West Papua and highlight the importance of protecting seagrass beds, particularly deep water beds dominated by *Halophila/Halodule* species, and reducing threats from fishing gears and illegal hunting.

### 4.5. Crocodiles

All four crocodile species found in Indonesia are protected under national law. Crocodiles have been hunted for their valuable skins in Papua since the colonial period, though very little data are available on the distribution and status of populations in the BHS. Saltwater *Crocodylus porosus* and freshwater *Crocodylus novaeguineae* populations have been documented in the Mamberamo delta and Cendrawasih Bay in the northern BHS (WWF, 2003) as well as in Bintuni and Arguni Bays in the southern BHS, while remnant populations of saltwater crocodiles have also been observed in Yapen, Mayalibit Bay, and Waigeo, Batanta and Misool islands. Recent coastal development, including the filling in of brackish streams and the destruction of nesting beaches for road construction, is reducing available crocodile habitat in the BHS.

## 5. Resource use and threats to coastal and marine ecosystems

Despite having the highest marine biodiversity, the richest fisheries resources, the most extensive intact lowland rainforests in Indonesia, and vast energy reserves in the oil and gas sectors, the BHS has the highest levels of poverty in the country (Resosudarmo and Jotzo, 2009). Over 40% of the 761,000 people living in the BHS fall below the poverty line (2010 census, Central Statistics Agency). Since the early 1960s the Indonesian government has implemented transmigration programs to encourage families from overpopulated islands in Indonesia, to settle in West Papua and Papua provinces and develop an export agricultural sector (Petocz, 1989; GRM International, 2009). The region exports small quantities of crops such as palm oil, nutmeg, cacao and coffee, but the main resources are fish, primary forest timber and rich deposits of oil, gas and minerals. Economic growth rates are very high in the region, averaging 10% per annum from 2001 to 2005 (GRM International, 2009); unfortunately this is driven primarily by migrant workers and the indigenous Papuan communities see little benefit from this growth (Resosudarmo and Jotzo, 2009).

While coastal and marine ecosystems here are no longer pristine and the fishery stocks of some areas are severely depleted – in some cases up to an order of magnitude decline since the 1970s (Ainsworth et al., 2008) – low human population density and environmental factors have kept them relatively healthy compared to many other areas of Southeast Asia (Ainsworth et al., 2008; Burke et al., 2011). However, unsustainable exploitation—both legal and illegal—of natural resources, irresponsible development practices, and the BHS's rapid human population growth rate (5.5% per year, 2010 census, Central Statistics Agency), threaten the health of these ecosystems and the local communities who depend on them. The following section provides a summary of resource uses and threats to coastal and marine ecosystems in the BHS.

### 5.1. Fisheries

Fisheries provide a main source of income and food to coastal people throughout the BHS (e.g. Larsen et al., 2011). Traditional subsistence fishing – predominantly using handlines from small canoes – was the only form of fishing in the region prior to the 1960s and is still extensively practiced today. The introduction of commercial fisheries – both legal and illegal – in the 1960s heralded a rapid decline in fishery resources due to over-exploitation (Palomares et al., 2007). The introduction of destructive fishing methods such as bomb fishing, cyanide and compressor fishing in the 1980s further contributed to the decline of fishery resources. By the 1990s some fisheries were reporting a decline of up to 90% in catch per unit effort (Ainsworth et al., 2008). While the use of destructive fishing methods has been curtailed by the arrival of conservation NGOs in the early 2000s and outreach campaigns on the impacts of destructive fishing, the underlying social and economic climate which promotes illegal, unregulated and unreported (IUU) fisheries continues throughout Indonesia (Heazle and Butcher, 2007).

Despite fishing being the primary livelihood of coastal people in the BHS, there is little published or current data on how much this sector contributes to the local economy and how much money is generated as a local tax income for regency and provincial governments. In the BHS, there is a diverse base of fisheries including invertebrates (sea cucumber, *Trochus*, giant clams, lobster), lift net fisheries (anchovy, sardine and squids), reef fisheries (snapper and grouper), coastal and pelagic shark fisheries, and small and large pelagic fisheries (Indian and Spanish mackerel, big-eye tuna, skipjacks and trevally species). Large shrimp fisheries operate in Bintuni Bay which have increased in intensity since the 1990s as a result of an increase in the number and size of boats and the introduction of improved catch techniques and technology (Pet-Soede et al., 2006). Most fishing gears are used in the BHS including factory trawling along the Fakfak-Kaimana coastline, a gear type that is illegal thoughout Indonesia except in the Arafura Sea.

The live reef fish trade has operated in the BHS since the 1980s targetting larger grouper species, snappers and Napoleon wrasse (*Cheilinus undulatus*) (Sadovy and Liu, 2004). This fishery has been particularly devastating because of the practice of targetting spawning aggregations and its inherent boom-and-bust nature (Mangubhai et al., 2011). The use of cyanide and compressor by both local and outside fishers, particularly from Sulawesi, has caused the rapid decline in Napoleon wrasse in Raja Ampat from 1985 to the late 1990s (Sadovy and Liu, 2004). During this period, local fishers could not stop outsiders from using destructive fishing methods, as boats were often accompanied by military or police officers. To date, only one significant grouper spawning aggregation (>300 individuals) has been recorded in the BHS in Raja Ampat (Wilson et al., 2010b). This remaining aggregation is now closed to fishing but remains vulnerable to over-exploitation by adjacent fisheries in migratory corridors during spawning seasons. This pattern of exploitation is consistent with those recorded across Indonesia, where grouper spawning aggregations have largely disappeared (Wilson et al., 2010b; Mangubhai et al., 2011). Current efforts by the Indonesian government to finally regulate this fishery, particularly for slow growing species, may be ineffective.

An assessment of fish stocks versus reported fish catches in Raja Ampat estimated that illegal, unreported and unregulated (IUU) fishing accounted for more than 20% of reef fisheries catches (Varkey et al., 2010). Fisheries with more than 50% of the catch estimated as IUU include shark, tuna, and anchovy (see Table 1 in Varkey et al., 2010), with IUU fisheries valued at USD $40 million in 2006. Anchovy are caught using lift nets (*bagan*) and in some cases mesh sizes are so fine that the catch consists primarily of juveniles. This unregulated fishery produces hundreds of tonnes of fish which are either dried for human consumption or used as live bait for tuna fisheries. A study of the lift net fishery in one bay in Raja Ampat estimated that 2493–4468 tonnes of anchovy were caught each year with a total value of USD $1.2–2.1 million (Bailey et al., 2008). These types of operations are common throughout Indonesia and are largely operated by outside fishers from Sulawesi or other parts of Indonesia. Other than the loss of potential revenue for the local government, the effects of unregulated harvest of the base of the food chain is likely to impact not only the productivity of larger prey species such as tuna but also endangered species such as baleen whales that frequent the area.

Overall, there is little information on current fisheries trends in the BHS with almost all fisheries operating in the absence of critical information on stocks, few management regulations and little or sporadic enforcement. Pelagic fisheries in northern BHS and shrimp fisheries in southern BHS are already considered over exploited by the Indonesian government. While there is a growing interest in applying ecosystem based approaches to fisheries management in Indonesia, the concept is still relatively new with no examples of how to best apply this model. With the exception of MPAs in the BHS where there are some efforts to manage local and commercial fisheries (see Section 6), coordinated efforts to manage coastal or pelagic fisheries sustainably are largely absent in the region. Though there are some encouraging signs of governmental interest in improving fisheries management, in the absence of critical baseline information on fish, shark and invertebrate stocks and poor enforcement of existing regulations, fisheries stocks will likely continue to decline in the BHS.

### 5.2. Tourism

The past 10 years have seen a dramatic expansion of marine tourism in the BHS as the region has developed a reputation as one of the top diving destinations on the planet (Jones et al., 2011). In Raja Ampat alone, the industry has expanded from a single diving resort and one live-aboard dive vessel visiting the area in 2001 (with a combined total of approximately 300 guests/year) to 8 resorts and over 40 dive live-aboard boats servicing over 6400 guests per year in 2011. Tourism development is comparatively at an earlier stage in Cendrawasih Bay and Kaimana's Triton Bay, though recent cover features in international dive magazines on both of these destinations have attracted global attention and there are now 6–10 dive liveaboard vessels offering trips to both.

In order to ensure benefits to the local economy, the Raja Ampat regency government developed a tourism entrance fee system in 2007 that requires every guest visiting the regency to pay Rp. 500,000 (approximately USD $55) for a waterproof tag valid for the calendar year. Thirty percent of the tag revenues are utilized by the government for tourism management, while 70% fund conservation and community development programs in all 135 villages of Raja Ampat. Since its inception, the fee system has accrued nearly USD $1,000,000 and has funded a nutrition program for pregnant and nursing mothers and MPA enforcement and turtle rookery guarding programs. Kaimana Regency and the Cendrawasih Bay National Park have recently commenced their own entrance fee systems.

The Raja Ampat government enacted legislation in July 2011 to establish the first marine tourism licensing system in Indonesia, setting an upper limit of 40 liveaboard dive vessel and 20 dive resort licenses for the regency while also stipulating strong requirements for environmentally-sensitive construction of resorts and employment of local community members in tourism operations. Both the West Papua provincial government and the Raja Ampat regency government have now explicitly recognized marine tourism as one of the main sectors for economic development of the regency, and increasingly this sector is providing benefits to local communities not only through entrance fee revenues, but also through direct employment in resorts and on dive vessels as well as through providing important markets for sale of handicrafts and of fish, fruits and vegetables harvested by community members.

### 5.3. Mariculture and aquaculture

The largest mariculture industry in the BHS is pearl oyster farming. There are currently two large pearl farms in Kaimana and seven pearl farms in Raja Ampat. The pearl farms focus exclusively on silver and gold pearls from the oyster *Pinctada maxima*. The industry operates in sheltered bays with unpolluted waters, low sedimentation, high dissolved nutrient levels, good water exchange and relatively stable cool water temperatures. Pearl farming companies enter into private lease agreements with local

Papuan communities over large areas of water, generally have low environmental impact and can provide strong socioeconomic benefits for local communities. Cendana Indopearls for example, employs around 200 staff, provides training and livelihoods for many members of the community, and supplies electricity, transportation, medical services and schooling for the two local communities in Raja Ampat with whom they have their lease agreements. While the overall contribution of pearl farms to the local economy is not known, it is estimated that Cendana Indopearls invests nearly USD $3 million per annum into the local economy in the form of operational costs, salaries, rents, royalties and taxes (J. Taylor, personal communication). Additionally, pearl farm waters are well-patrolled and serve as de facto marine reserves.

The Raja Ampat Marine Affairs and Fisheries Agency established a grouper hatchery in mid-2011 focusing on highfin grouper (*Cromileptes altivelis*) to support community grow-out of hatchery grouper to reduce pressure on wild stocks which are largely depleted in the region. The larvae are currently being sourced from outside the region during the trial phase, but it is hoped that once a local brood stock has been established fingerlings can be sourced from Raja Ampat to minimize genetic mixing of stocks and introduction of pathogens. Seaweed has also been established in Raja Ampat and Kaimana Regencies and Cendrawasih Bay, with several villages now actively cultivating Eucheumoid algae for sale to the carrageenan industry. More recently, villages in Mayalibit Bay in Raja Ampat are trialing mangrove crab (*Scylla serrata*) grow-out, whereby juvenile crabs are collected and placed in pens constructed in healthy mangrove forest environments for grow-out. With the exception of pearl farms, other mariculture and aquaculture efforts are still in their infancy in the region.

### 5.4. Oil, gas and mineral mining

The BHS is not only rich in renewable natural resources but also in crude oil, gas and minerals such as gold, copper and nickel. The region's main mining products are oil and gas located in the regencies of South Sorong, Bintuni Bay, and Fakfak and Kaimana. The most controversial mine in Eastern Indonesia is Indonesia's (and the world's) largest open-cut gold and copper Grasberg mine, owned by Freeport Indonesia, that provides nearly 50% of Papua province's GDP and is the largest tax payer to the Indonesian government (Resosudarmo and Jotzo, 2009). The company is responsible for the discharge of 125,000 tonnes/day of mine tailings into the Ajkwa River (Brunskill et al., 2004), and associated environmental damage. Although mineral mines in West Papua are comparatively smaller, companies frequently operate without proper control of excavation run-off (Fig. 10a), and with little to no social responsibility.

The Indonesian government is committed to increasing its overall hydrocarbon production to meet its target of 960,000 barrels/day. Government policies are being revised to encourage the rapid expansion of oil and gas exploration and production throughout the Indonesian archipelago, including the Makassar Strait, North Ceram Sea, Halmahera and Papua (especially Cendrawasih Bay, Raja Ampat and Kaimana in the BHS). Contracts can be issued to local or foreign companies to operate in 'Mining Areas' that have been designated by the national government. Currently, the largest gas project 'Tangguh Liquefied Natural Gas' is positioned to extract natural gas from fields in the Bintuni Bay area for export to countries outside of Indonesia. With reserves of 14.4 trillion cubic feet, this gas field is predicted to generate USD $3.6 billion for the government of West Papua and USD $8.7 billion for the national government over the next 20 years (GRM International, 2009).

Oil and gas exploration has increased in the BHS. Since early 2010, at least four vessels have conducted seismic surveys for seabed oil and gas deposits in Raja Ampat, close to Kofiau, Salawati and Misool Islands. These large specialized ships tow cables that fire airgun blasts/sound waves at the seabed to elucidate underwater geological formations and structures. Potential impacts from unregulated seismic surveys include disturbance to migratory species such as cetaceans and turtles which can become displaced (McCauley et al., 2000), lethal and sub-lethal effects on adult fish, fish larvae or fish eggs (Hirst and Rodhouse, 2000), and negative impacts to community fisheries (Skalski et al., 1992; Hirst and Rodhouse, 2000). Although the vessels had licenses from the national government, the surveys were conducted within 4 nautical miles

**Fig. 10.** Photographs showing the land-based impacts to marine environment from poorly planned coastal development or marine use activities. Photograph sources in parentheses: (a) mining on Waigeo Island (Indrah/CI); (b) reclamation of reefs and poorly planned roads on Waigeo Island (C. Huffard/CI); (c) filling in of small streams and rivers for road development (C. Huffard/CI); and (d) Damage during the floods and mud slides at Wasior, adjacent to Cendrawasih Bay (WWF-Indonesia).

of the coast without the approval of the provincial or regency governments, and without public consultation or adherence to international standards. This issue highlights the lack of coordination between national, provincial and regency governments in the energy sector.

### 5.5. Deforestation and coastal development

Deforestation and coastal development have escalated over the last 10 years in the BHS, and are leading to yet unmeasured, but nonetheless observable impacts on watersheds, coastlines and marine environments (Fig. 10). Highly erodible soils, very steep slopes and high rainfall (Fig. 3) in the BHS makes coastal habitats (particularly shallow coral reefs), more vulnerable to damage from land based activities. One or more authors are aware of impacts from deforestation and poorly planned coastal development including: (a) run-off of topsoil to beaches and marine habitats causing smothering of coral and soft-sediment communities; (b) loss of mangroves due to road construction and logging; (c) direct loss of critical habitat for threatened species (e.g. green, hawksbill, and leatherback turtles, estuarine crocodiles, and Wilson's Bird of Paradise *Cicinnurus respublica*) through beach modification and coastal vegetation removal; (d) direct loss of coral reefs through reclamation; (e) altered salinity and temperature profiles at river mouths due to interrupted water flow; and (f) introduction of invasive species to forests.

It has been estimated that 85% of Papua is still covered with intact forests (GRM International, 2009). However, most of the lowland forests have been designated for logging and agriculture. There is extensive logging in the Bomberai Peninsula between Fakfak and Kaimana, and the Wandammen Peninsula in Cendrawasih Bay (M.V. Erdmann, personal observations). As far back as 2002, illegal logging has been taking place on the islands of Waigeo and Batanta in Raja Ampat, including in three gazetted nature reserves (McKenna et al., 2002) and appears to be increasing as infrastructure improves to support the capital of Raja Ampat. In addition, the Indonesian government is committed to establish 5.6 million ha of oil palm plantations over the next decade, particularly in Sumatra, Kalimantan and Papua to meet global demands for biofuels (GRM International, 2009). There are well established plantations on the south coast of Bintuni Bay and northern Manokwari regency, with plans for expansion to primary lowland forests in Sorong, South Sorong, Fakfak and Kaimana regencies. If logging and the conversion of land for agriculture in coastal areas is poorly managed, there will be increasing risk of negative impacts on coastal biodiversity and adjacent marine environments. Given the scale and remoteness of many areas in the BHS, much of the impacts or loss in biodiversity is likely to go undocumented.

### 5.6. Climate change

In addition to the anthropogenic threats detailed above, coastal and marine areas in the BHS are threatened by a combination of climate change impacts – increased frequency and severity of elevated SSTs and extreme weather events, sea-level rise and ocean acidification. Similar to other regions, it is expected that sea-level rise in the BHS will result in increased coastal erosion, inundation and displacement of wetlands and coastal lowlands, increased flood and storm damage, and saltwater intrusion into freshwater sources (Klein and Nicholls, 1999). All of the important turtle nesting beaches in the BHS (including Abun, Sayang/Piai, Venu, Sabuda Tuturuga, and Wairundi) have experienced significant beach erosion over the past 5 years, causing the death of hundreds of turtle eggs.

To date, the BHS has not recorded severe coral bleaching events caused by extreme SST as recorded in some Indian Ocean and Pacific Ocean locations. However, the magnitude and frequency of thermal stress events severe enough to cause bleaching is predicted to increase more than two fold in the BHS over the next 100 years (McLeod et al., 2010). Small-scale coral bleaching was recorded in March 2010 and 2011 in MPAs in Kofiau, Southeast Misool, Mayalibit Bay, Dampier Strait with no significant mortality was recorded during subsequent reef health surveys (Table 1). However, in 2010–2011 Cendrawasih Bay experienced large scale bleaching with some reefs recording 90% mortality. The lack of mortality in Raja Ampat and Kaimana, suggests that large temperature variation (Fig. 5a–h) may confer some level of resistance to bleaching, whereas Cendrawasih with low temperature variation (Fig. 5i and j) may be more vulnerable to thermally induced bleaching events, as has been observed elsewhere (e.g. Ateweberhan and McClanahan, 2010). Given the reliance of local communities on fisheries and other coastal resources, including groundwater for consumption and crop irrigation, climate change impacts resulting from sea level rise and heat stress and related coral leaching and mortality may likely affect their future livelihoods and food security.

## 6. Management and protected measures

### 6.1. National and traditional laws of governance

Special autonomy was granted in 2001 (Law 21/2001) by the National government to enable provincial and regency governments in Papua to self-govern and manage their economic development. Local governments were given authority to manage the majority of their affairs except for those related to international politics, national security, and fiscal and monetary policy (Resosudarmo and Jotzo, 2009). Although overall national policies are developed by the national government and guide nature conservation in Indonesia, implicit in the autonomy law is the rights of indigenous Papuans to protect, manage and exploit their natural resources, including fisheries and forests.

Indigenous Papuan communities have long-ago established a system of territorial use rights fisheries to manage the access of family clans to reefs in the BHS, which is fundamental to their societal structure (Donnelly et al., 2003; McLeod et al., 2009). The customary ('*adat*') law is a set of unwritten laws, which regulate the rights and duties of indigenous communities, including towards their natural resources. Traditional systems of tenure for land and sea are highly complex and highly variable across Papua (McLeod et al., 2009). Land and sea tenure is not written into formal law, but passed on verbally from one generation to another with resource rights vested in individuals, families, clans or entire communities. Consequently there is very little formal private land ownership in Papua, though communities have the rights to lease their areas to outsiders or give permission to outsiders to exploit their natural resources.

Many coastal Papuan communities in eastern Indonesia also implement a traditional system of natural resource management on the land and in the sea called '*sasi*'. In the sea, *sasi* most often involves temporal closures of specific fisheries resources (e.g. sea cucumbers, *Trochus*) or fisheries areas for periods ranging from 6 months to 5 years (McLeod et al., 2009). The degree to which *sasi* and other conservation-oriented customary practices are honored by villages throughout the BHS varies from full compliance to disuse.

### 6.2. Marine protected areas

MPAs or MPA networks are seen as a key tool to address in water threats to BHS reefs and to contribute to biodiversity conser-

**Table 2**
Marine protected areas (MPAs) in the Bird's Head Seascape. MPA type: KKPD = Kawasan Konservasi Perairan Daerah (Regional Marine Protected Area), KKPN = Kawasan Konservasi Perairan Nastional (National Marine Conservation Area), TN = Taman Nasional (National Park), SM = Suaka Margasatwa (Wildlife Santuary) SML = Suaka Margasatwa Laut (Marine Wildlife Sanctuary), TWA = Taman Wisata Alam (Nature Tourism Park), CA = Cagar Alam (Strict Nature Reserve). MPA designation legislation: Perbup = Peraturan Bupati (head of government decree), Perda = Peraturan Daerah (regency law), SK = Surat Keputusan (Government decree). Managing agency: KKP = Kementrian Kelautan dan Perikanan (Ministry of Marine Affairs and Fisheries), DKP = Dinas Kelautan dan Perikanan (Regency Marine Affairs and Fisheries Agency), PHKA = Perlindungan Hutan dan Konservasi Alam (Department of Forest Protection and Nature Conservation), BBKSDA = Balai Besar Konservasi Sumber Daya Alam (Regional Office of Nature Conservation), BTNTC = Balai Taman Nasional Teluk Cendrawasih (Cendrawasih National Park Management Authority). RI = Republic of Indonesia.

| Regency | MPA name | MPA type | Size (ha) | MPA designation legislation | Managing agency | Conservation values |
|---|---|---|---|---|---|---|
| Kaimana | Kaimana | KKPD | 597,747 | Perbup Kaimana No. 4/2008 | DKP | Soft-coral dominated reefs in unique low-salinity environment. Large, mostly intact mangrove and nipah palm bays, including inland saltwater fjord of Arguni Bay. Abundant saltwater crocodiles. Nesting hawksbill and green turtles. Whale shark aggregations. Resident populations of Bryde's whales and Indo-Pacific humpback dolphins. Paleolithic coastal rock art. |
| Fakfak | Sabuda Tataruga | SML | 5000 | SK Menteri Kehutanan RI No. 82/Kpts-II/1993 | PHKA | Offshore set of low coral cay islands with expansive green turtle nesting beaches. Suspected use of nesting beaches by flatback turtles. |
| Raja Ampat | Southeast Misool | KKPD | 343,200[a] | Perbup No. 66/2007, Perda No. 27/2008, Perbup No. 5/2009 | DKP | High diversity of reef types. Diverse sea fans and soft coral communities. Large, intact marine lakes. Resident crocodiles. Nesting hawksbill turtles. Manta aggregations. Unique limestone karst ecological features. Rock paintings, sacred caves and other cultural sites. |
| Raja Ampat | Kofiau and Boo islands | KKPD | 170,000 | Perbup No. 66/2007, Perda No. 27/2008, Perbup No. 5/2009 | DKP | High diversity of reef types. Important area for migratory whale species as well as dolphins. Coconut crab populations. Diverse species of small fish. Variety of lagoon habitats. Endemic bird species. |
| Raja Ampat | Dampier Strait | KKPD | 303,200 | Perbup No. 66/2007, Perda No. 27/2008, Perbup No. 5/2009 | DKP | Extensive fringing and patch reef habitat subject to frequent upwellings and strong currents. Manta aggregation sites. Grouper spawning aggregation. Populations of dugongs and coconut crabs. Major cetacean corridor for sperm whales, orcas, numerous species of dolphin and blackfish. Scattered crocodile populations. |
| Raja Ampat | Mayalibit Bay | KKPD | 53,100 | Perbup No. 66/2007, Perda No. 27/2008, Perbup No. 5/2009 | DKP | Large mangrove-lined bays and extensive seagrass beds. Unique sponge and filter-feeder dominated reefs. Spawning aggregations of Indian and Spanish mackerel. Indo-pacific humpback dolphins. Remnant crocodile and dugong populations. |
| Raja Ampat | Kawe[b] | KKPD | 155,000 | Perbup No. 66/2007, Perda No. 27/2008, Perbup No. 5/2009 | KKP/KKPD | Unique rocky reefs subject to open oceanic swell, with associated system of large underwater caves. Regionally significant green & hawksbill turtle nesting beaches. Shark and ray pupping area in Wayag lagoon. Manta aggregations. Populations of coconut crabs. Spectacular karst "beehive" formations. |
| Raja Ampat | Ayau-Asia | KKPD | 101,440 | Perbup No. 66/2007, Perda No. 27/2008, Perbup No. 5/2009 | DKP | Open oceanic atoll system unique within the Bird's Head, with extensive atoll lagoon habitat and sheer reef drop-offs to 1000s m depth. Green turtle nesting beaches. Aggregations of dolphins and manta rays. Regionally significant reef fish spawning aggregation sites (including grouper and Napoleon wrasse). |
| Raja Ampat | Panjang islands | KKPN | 60,000 | SK Menteri Kelautan dan Perikanan No. 64/2009 | KKP | Extensive coastal fringing reefs and mangrove forests. Large baitfish aggregations. Remnant grouper spawning aggregation sites. Scattered dugong and crocodile populations. |
| Tambrau | Abun Jamursba-Medi[c] | KKPD<br>SM | 169,515<br>27,825 | SK Bupati Sorong No. 142/2005, SK Menteri Kehutanan dan Perkebunan No. 891/Kpts-II/1999 | PHKA<br>BBKSDA | Extensive sandy beaches and lowland rainforests. BBKSDA Globally significant leatherback turtle nesting beaches (largest Pacific leatherback rookery in the world). Nesting habitat for Olive Ridley, greens and hawksbill turtles. |
| Wondama Bay, Nabire | Cendrawasih Bay[d] | TN | 1,453,500 | SK Menteri Kehutanan RI No. 8009/Kpts-II/2002 | PHKA<br>BBTNTC | Indonesia's second largest marine national park. High diversity of habitats within a large deep-water and semi-enclosed bay. Healthy dugong and crocodile populations. Whale sharks. At least 15 endemic coral reef fish species and many unique haplotypes of a wide range of marine organisms (due to geographic isolation of populations within bay). Nesting habitat for the green and hawksbill turtle, and feeding area for leatherback and olive ridley turtle. |
| Biak-Numfor | Padaido | TWA | 183,000 | SK Menteri Kelautan dan Perikanan RI No. 68/2009 | KKP | Extensive fringing reefs in an archipelago of small islands rising out of deep water and exposed to largely oceanic conditions. High cetacean diversity including sperm whales and orcas. Hammerhead shark aggregations. Remnant turtle nesting beaches. |

[a] There is a current proposal to expand this MPA to 366,000 ha.
[b] KKPD Kawe is also overlaid by a more recent gazettement of KKPN West Waigeo (as per SK Menteri Kelautan dan Perikanan RI No. 65/2009); it is however, likely to be managed as part of the Raja Ampat KKPD network.
[c] The SML overlaps with the KKPD, though is smaller in size.
[d] Cendrawasih Bay is sometimes spelt Cenderawasih Bay in some government documents.

vation and sustainable fisheries (Coral Triangle Initiative, 2009). The identification of critical marine areas for protection and management first began in the BHS in the early 1990s, mostly initiated by WWF/IUCN, and followed by a number of conservation projects that focused on community empowerment in implementing marine resource management. Since then, conservation initiatives have grown and there are currently 12 MPAs in the BHS with active management in place, ranging in size from 5000 to 1,453,500 ha and covering a total area of 3,594,702 ha (Fig. 1; Table 2). This figure includes Cendrawasih Bay National Marine Park, which is the second largest MPA in Indonesia covering 1,453,500 ha, and the Kaimana MPA which covers all of Kaimana's jurisdictional waters (597,747 ha). The majority of the MPAs in the BHS have been established and gazetted 'bottom up' through community customary *adat* declarations and regency laws, and reinforced by national laws. MPAs in the BHS are integrating traditional practices such as *sasi* into MPA zoning and management, and developing co-management structures that allow communities to actively manage and patrol their MPAs.

The majority of the MPAs in the BHS are in Raja Ampat regency, which has a network of seven MPAs covering 1,185,940 ha of coral reef habitat and associated small islands (Fig. 1; Table 2). Current efforts are underway to institutionalize the Raja Ampat MPA network under a co-management body (termed '*Badan Layanan Umum Daerah*' or regency technical unit) and framework that has been successfully applied to hospitals in many parts of Indonesia. This public–private co-management model provides two major benefits compared to traditional Indonesian governance of MPAs. Firstly, it allows the management body to largely manage its own finances, including both governmental budget allocations and grants from aid agencies and private donors, as well as any revenues generated (e.g. tourism entrance fees). Secondly, it allows non-government partners to sit on the management board and private individuals to be recruited as MPA staff and paid a professional (i.e., non-civil servant) salary. If successful, this co-management model has the potential to be applied to other MPA networks that are being developed in Indonesia (Coral Triangle Initiative, 2009).

The long term success of MPAs in the BHS will mostly depend on the management of waters outside MPAs and an integrated approach to coastal management across the BHS. Since 2007 and the passing of laws relating to spatial planning (Law 26/2007) and management of coastal areas and small islands (Law 27/2007), the Indonesian Government has provided a legal framework to reform spatial planning processes and achieve more effective and integrated urban and rural planning and sectoral development, and enable greater synergies between spatial plans developed at the regency, province and at the national level. In the BHS, through the efforts of international and national NGOs there has been a push for coastal development, fisheries, spatial planning and species management to align with the principles of 'ecosystem-based management' and recognize that ecosystems, communities, and economic opportunities are strongly connected.

## 7. Future for the Bird's Head Seascape

The BHS is currently struggling to keep up with rapid environmental, social and economic change. Local communities and the regional economy rely heavily on natural resources – both terrestrial and marine – for industries such as fishing, mining, forestry, oil and gas, mariculture and tourism. However, certain activities associated with these industries threaten the biodiversity and health of marine and terrestrial ecosystems in the BHS. Biodiversity conservation is increasingly an economic issue of growing importance, where the future prosperity of this region will depend on policies and management which support sustainable industries for the benefit of local communities and protect the outstanding biodiversity of this region.

The Seascape is at a critical juncture at which local governments require strong technical advice and increased capacity to balance development pressures with sustainable management of their coastal and marine resources. Although capacity to manage marine resources is slowly increasing through the combined efforts of government and NGOs, local governments still and stakeholders require support in developing effective and sustainable coastal and marine resource management. The current focus on capacity building of government staff in marine management in the BHS (which is linked to a larger national program by the Ministry of Marine Affairs and Fisheries to build MPA training centers across Indonesia) is both crucial and timely. Low population numbers, relatively healthy natural resources and a strong tenure system in Papua, provide a real opportunity for government and local communities to manage their resources sustainably, ensure long-term food security, while meeting their development aspirations. The empowerment of local governments and local communities to manage these resources is critically important for the future sustainability and food security of the BHS.

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## Appendix A. Supplementary data

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## References

Ainsworth, C.H., Pitcher, T.J., Rotinsulu, C., 2008. Evidence of fishery depletions and shifting cognitive baselines in Eastern Indonesia. Biological Conservation 141, 848–859.

Allen, G.R., Erdmann, M.V., 2008. Two new species of bamboo sharks (Orectolobiformes: Hemiscyllidae) from western New Guinea. Aqua, International Journal of Ichthyology 13, 93–108.

Allen, G.R., Erdmann, M.V., 2009. Reef fishes of the Bird's Head Peninsula, West Papua, Indonesia. Check List 5, 587–628.

Allen, G.R., Erdmann, M.V., 2012. Reef Fishes of the East Indies. Volumes I–III. Tropical Reef Research, Perth.

Alongi, D.M., 2007. Mangrove forests of Papua. In: Marshall, A.J., Beehler, B. (Eds.), The Ecology of Papua (Part Two). Periplus, Singapore, pp. 824–857.

Ateweberhan, M., McClanahan, T.R., 2010. Relationship between historical sea-surface temperature variability and climate change-induced coral mortality in the western Indian Ocean. Marine Pollution Bulletin 60, 964–970.

Bailey, M., Rotinsulu, C., Sumaila, U., 2008. The migrant anchovy fishery in Kabui Bay, Raja Ampat, Indonesia: Catch, profitability, and income distribution. Marine Policy 32, 483–488.
Becking, L.E., Renema, W., Dondorp, E., 2009. Marine Lakes of Raja Ampat, West Papua, Indonesia. General Overview of First Sightings. National Museum of Natural History – Naturalis, The Netherlands.
Becking, L.E., Renema, W., Santodomingo, N.K., Hoeksema, B.W., Tuti, Y., de Voogd, N.J., 2011. Recently discovered landlocked basins in Indonesia reveal high habitat diversity in anchialine systems. Hydrobiologia 677, 89–105.
Benson, S., Dutton, P., Hitipeuw, C., Samber, B., Bakarbessy, J., Parker, D., 2007. Post-nesting migrations of leatherback turtles (*Dermochelys coriacea*) from Jamursba-Medi, Bird's Head Penninsula, Indonesia. Chelonian Conservation and Biology 6, 150–154.
Benson, S.R., Eguchi, T., Foley, D.G., Forney, K.A., Bailey, H., Hitipeuw, C., Samber, B.P., Tapilatu, R.F., Rei, V., Ramohia, P., Pita, J., Dutton, P.H., 2011. Large-scale movements and high-use areas of western Pacific leatherback turtles, *Dermochelys coriacea*. Ecosphere 2 (84), 1–27.
Brunskill, G.J., Zagorskis, I., Pfitzner, J., Ellison, J., 2004. Sediment and trace element depositional history from the Ajkwa River estuarine mangroves of Irian Jaya (West Papua), Indonesia. Continental Shelf Research 24, 2535–2551.
Burke, L., Reytar, K., Spalding, M., Perry, A., 2011. Reefs at risk revisited. World Resources Institute, The Nature Conservancy, World Fish Center, International Coral Reef Action Network, UNEP world conservation monitoring centre and global coral reef monitoring network, Washington DC.
Coral Triangle Initiative, 2009. Regional Plan of Action on Coral Triangle Initiative on Coral Reefs, Fisheries and Food Security. Interim Regional CTI Secretariat, Indonesia.
Crandall, E.D., Jones, M.E., Munoz, M.M., Akinronbi, B., Erdmann, M.V., Barber, P.H., 2008. Comparative phylogeography of two seastars and their ectosymbionts within the Coral Triangle. Molecular Ecology 17, 5276–5290.
de Iongh, H.H., Hutomo, M., Moraal, M., Kiswara, W., 2009. Scientific Report Part I. National Strategy and Action Plan for the Dugong in Indonesia. Institute of Environmental Sciences, Leiden.
DeBoer, T.C., Subia, M.D., Ambariyanto, Erdmann, M.V., Kovitvongsa, K., Barber, P.H., 2008. Phylogeography and limited genetic connectivity in the endangered boring giant clam across the Coral Triangle. Conservation Biology 22, 1255–1266.
DeVantier, L., Turak, E., Allen, G., 2009. Reef-scapes, Reef Habitats and Coral Communities of Raja Ampat, Bird's Head Seascape, Papua, Indonesia. The Nature Conservancy, Bali.
Dimara, R., Fauzan, A., Lazuardi, M., Pada, D., Allen, G.R., Erdmann, M.V., Huffard, C.L., Katz, L.S., Winterbottom, R., 2010. Pisces, Teleostidae, Gobiidae, illustrated list of additions to the fauna of the Raja Ampat Islands, Indonesia. Check List 6, 619–625.
Donnelly, R., Neville, D., Mous, P.J., 2003. Report on a rapid ecological assessment of the Raja Ampat Islands, Papua, Eastern Indonesia held October 30 – November 22, 2002. The Nature Conservancy, Bali.
English, S.E., Wilkinson, C., Baker, V., 1997. Survey Manual for Tropical Marine Resources. Australian Institute of Marine Science, Townsville.
Firman, A., Azhar, I., 2006. Atlas Sumberdaya Pesisir Raja Ampat Provinsi Irian Jaya Barat. Pemerintah Kabupaten Raja Ampat, Sorong.
Gandi, Y., Hardiono, M., Rahawarini, Y., Nugrohoi, J., Manusawai, J., 2008. Interpretation of mangrove ecosystem dynamic in Bintuni Bay Nature Reserve using geographic information system. Biodiversitas 9, 156–159.
Gordon, A.L., 2005. Oceanography of the Indonesian Seas and their flow-through. Oceanography 18, 14–27.
Gordon, A.L., Fine, R.A., 1996. Pathways of water between the Pacific and Indian oceans in the Indonesian seas. Nature 379, 146–149.
Green, A.L., Mous, P.J., 2008. Delineating the Coral Triangle, Its Ecoregions and Functional Seascapes. Version 5.0. Report1/08. The Nature Conservancy, Bali.
GRM International, 2009. Papua Assessment USAID/Indonesia, Final Report. GRM International, Jakarta.
Heazle, M., Butcher, J.G., 2007. Fisheries depletion and the state in Indonesia: towards a regional regulatory regime. Marine Policy 31, 276–286.
Heron, S., Willis, B., Skirving, W., Eakin, M., Page, C., Miller, I., 2010. Summer hot snaps and winter conditions: modelling white syndrome outbreaks on Great Barrier Reef corals. PLoS One 5 (8), e12210. http://dx.doi.org/10.1371/journal.pone.0012210.
Hirst, A.G., Rodhouse, P.G., 2000. Impacts of geophysical seismic surveying on fishing success. Reviews in Fish Biology and Fisheries 10, 113–118.
Hitipeuw, C., Dutton, P., Benson, S., Thebu, J., Bakarbessy, J., 2007. Population status and internesting movement of leatherback turtles, *Dermochelys coriacea*, nesting on the northwest coast of Papua, Indonesia. Chelonian Conservation and Biology 6, 28–36.
Huffard, C.L., Erdmann, M.V., Gunawan, T., 2009. Defining Geographic Priorities for Marine Biodiversity Conservation in Indonesia. Coral Triangle Support Program, Jakarta.
Jones, B., Shimlock, M., Erdmann, M.V., Allen, G.R., 2011. Diving Indonesia's Bird's Head Seascape. Conservation International, Bali.
Kahn, B., 2007. Marine Mammals of the Raja Ampat Islands: Visual and Acoustic Cetacean Survey and Training Program. Apex Environmental, Bali.
Kahn, B., 2009. Marine Mammal Survey and Training in Triton Bay, West Papua, Indonesia: Management Implications for Resident Bryde's Whales. Apex Environmental, Bali.
Kahn, B., Gearheart, G., Tapilatu, R., 2006. Bintuni Berau Bay Rapid Ecological Assessment (REA) for Marine Mammals and Marine Reptiles: Initial evaluation of risk mitigation measures for Tangguh LNG Project, Papua, Indonesia. Technical Report AE-BP0601.
Kilpatrick, K.A., Podestá, G.P., Evans, R., 2001. Overview of the NOAA/NASA advanced very high resolution radiometer Pathfinder algorithm for sea surface temperature and associated matchup database. Journal of Geophysical Research 106, 9179–9197.
Klein, R.J.T., Nicholls, R.J., 1999. Assessment of coastal vulnerability to climate change. Ambio 28, 182–187.
Larsen, S.N., Leisher, C., Mangubhai, S., Muljadi, A., Tapilatu, R., 2011. Report on a Coastal Rural Appraisal in Raja Ampat Regency, West Papua, Indonesia. The Nature Conservancy, Bali.
Mangubhai, S., Muhammed, S., Suprayitno, Muljadi, A., Purwanto, Rhodes, K.L., Tjandra, K., 2011. Do not stop: the importance of seamless monitoring and enforcement in an Indonesian Marine Protected Area. Journal of Marine Biology, 1–11 (Article ID 501465).
Marsh, H., Eros, C., Penrose, H., Hugues, J., 2002. The Dugong (*Dugong dugon*) Status Reports and Action Plans for Countries and Territories in its Range. IUCN, Gland.
McCauley, R.D., Fewtreli, J., Duncan, A.J., Jenner, C., Jenner, M.-N., Penrose, J.D., Prince, R.I.T., Adhitya, A., Murdoch, J., McCAbe, K., 2000. Marine seismic surveys – a study of environmental implications. APPEA Journal, 692–708.
McKenna, S.A., Allen, G.R., Suryadi, S., 2002. A Marine Rapid Assessment of the Raja Ampat Islands, Papua Province, Indonesia. RAP Bulletin of Biological Assessment 22. Conservation International, Washington DC.
McKenzie, C.R., Coles, R., Erftemeijer, P., 2007. Seagrass ecosystems of Papua. In: The Ecology of Papua Part 2. Periplus, Singapore, pp. 800–823.
McLeod, E., Szuster, B., Salm, R., 2009. Sasi and marine conservation in Raja Ampat, Indonesia. Coastal Management 37, 656–676.
McLeod, E., Moffitt, R., Timmermann, A., Salm, R., Menviel, L., Palmer, M.J., Selig, E.R., Casey, K.S., Bruno, J.F., 2010. Warming seas in the Coral Triangle: coral reef vulnerability and management implications. Coastal Management 38, 518–539.
Palomares, M.L.D., Heymans, J.J., Pauly, D., 2007. Historical ecology of the Raja Ampat Archipelago, Papua Province, Indonesia. Historical Phil Life Science 29, 35–56.
Petocz, R., 1989. Conservation and Development in Irian Jaya: A Strategy for Rational Resource Utilization. E.J. Brill, Leiden.
Pet-Soede, L., Monintja, D., Wanggai, F., Bawole, R., Abdullah, Y., Rochani, A., Tokede, M.J., 2006. Sustainable Fisheries in Bintuni Bay. University of Papua, Manokwari.
Prentice, M.L., Hope, G.S., 2007. Climate of Papua. In: The Ecology of Papua Part 2. Periplus, Singapore, pp. 177–195.
Resosudarmo, B.P., Jotzo, F., 2009. Workign with Nature Against Poverty. Development, Resources and the Environment in Eastern Indonesia. Institute of Southeast Asian Studies, Singapore.
Rudolf, P., Smeenk, C., Leatherwood, S., 1997. Preliminary checklist of cetacea in the Indonesian Archipelago and adjacent waters. Zoologische Verhandilingen 312, 3–48.
Sadovy, Y., Liu, M., 2004. Report on the Current Status and Exploitation History of Reef Fish Spawning Aggregations in Eastern Indonesia. University of Hong Kong, Hong Kong.
Short, F.T., Carruthers, T.J., Dennison, W.C., Waycott, M., 2007. Global seagrass distribution and diversity: a bioregional model. Journal of Experimental Marine Biology and Ecology 350, 3–20.
Skalski, J.R., Pearson, W.H., Malme, C.I., 1992. Effects of sounds from a geophysical device on catch per unit effort in hook and line fishery for rockfish (*Sebastes* spp.). Canadian Journal of Fisheries and Aquatic Sciences 49, 1357–1365.
Spalding, M., Kainuma, M., Collins, L., 2010. World Atlas of Mangroves. Earthscan, London.
Tapilatu, R.F., Tiwari, M., 2007. Leatherback turtle, *Dermochelys coriacea*, hatching success at Jamursba-Medi and Wermon beaches in Papua, Indonesia. Chelonian Conservation and Biology 6, 154–158.
Tomascik, T., Mah, A.J., Nontji, A., Moosa, M.K., 1997. Seagrasses. In: Tomascik, T., Mah, A.J., Nontji, A., Moosa, M.K. (Eds.), The Ecology of the Indonesian Seas VIII, Part II. Oxford University Press, Oxford, pp. 829–906.
Varkey, D.A., Ainsworth, C.H., Pitcher, T.J., Goram, Y., Sumaila, R., 2010. Illegal, unreported and unregulated fisheries catch in Raja Ampat Regency, Eastern Indonesia. Marine Policy 34, 228–236.
Veron, J.E.N., DeVantier, L.M., Turak, E., Green, A.L., Kininmonth, S., Stafford-Smith, M., Peterson, N., 2009. Delineating the Coral Triangle. Galaxea 11, 91–100.
Vranes, K., Gordon, A.L., 2005. Comparison of Indonesian Throughflow transport observations, Makassar Strait to eastern Indian Ocean. Geophysical Research Letters 32, 1–5.
Wallace, C.C., Turak, E., DeVantier, L., 2011. Novel characters in a conservative coral genus: three new species of *Astreopora* (Scleractinia: Acroporidae) from West Papua. Journal of Natural History 45, 1905–1924.
Wilson, J., Green, A., 2009. Biological Monitoring Methods for Assessing Coral Reef Health and Management Effectiveness of Marine Protected Areas in Indonesia. The Nature Conservancy, Bali.
Wilson, J., Rotinsulu, C., Muljadi, A.M., Wen, W., Barmawai, M., Mandagi, S., 2010a. Spatial and Temporal Patterns in Marine Resource Use Within Raja Ampat Region from Aerial Surveys 2006. The Nature Conservancy, Bali.
Wilson, J., Rhodes, K.L., Rotinsulu, C., 2010b. Aggregation fishing and local management within a marine protected area in Indonesia. SPC Live Reef Fish Information Bulletin 19, 713.
WWF, 2003. Bismarck Solomon Sea Ecoregion Biophysical and Socio-Economic Assessment Report. Indonesian Territory-North Papua. WWF Indonesia Program, Bali.