The Bird's Head Seascape Marine Protected Area network—Preventing biodiversity and ecosystem service loss amidst rapid change in Papua, Indonesia

Article *in* Conservation Science and Practice · March 2021

DOI: 10.1111/csp2.393

19 authors, including:

Purwanto Purwanto
Coral Triangle Center
30 PUBLICATIONS 208 CITATIONS

Dominic Andradi-Brown
World Wildlife Fund
90 PUBLICATIONS 486 CITATIONS

Dariani Matualage
State University of Papua
4 PUBLICATIONS 1 CITATION

Awaludinnoer Ahmad
The Nature Conservancy
5 PUBLICATIONS 330 CITATIONS

Received: 21 August 2020 | Revised: 10 February 2021 | Accepted: 17 February 2021
DOI: 10.1111/csp2.393

CONTRIBUTED PAPER

Conservation Science and Practice
A journal of the Society for Conservation Biology
Open Access
WILEY

The Bird's Head Seascape Marine Protected Area network—Preventing biodiversity and ecosystem service loss amidst rapid change in Papua, Indonesia

Purwanto[1,2] | **Dominic A. Andradi-Brown**[3] | **Dariani Matualage**[1] | **Irman Rumengan**[1] | **Awaludinnoer**[4] | **Defy Pada**[5] | **Nur I. Hidayat**[5] | **Amkieltiela**[6] | **Helen E. Fox**[7] | **Matt Fox**[5] | **Sangeeta Mangubhai**[8] | **La Hamid**[9] | **Muhammad E. Lazuardi**[10] | **Ronald Mambrasar**[5] | **Nugraha Maulana**[5] | **Mulyadi**[9] | **Syafri Tuharea**[11] | **Fitryanti Pakiding**[1] | **Gabby N. Ahmadia**[3]

[1]University of Papua, Manokwari, West Papua, Indonesia
[2]Coral Triangle Center, Sanur, Bali, Indonesia
[3]Ocean Conservation, World Wildlife Fund, Washington, District of Columbia
[4]The Nature Conservancy, Indonesia Coasts and Oceans Program – Raja Ampat, Sorong, West Papua, Indonesia
[5]Conservation International Indonesia, Sorong, West Papua, Indonesia
[6]Conservation Science Unit, WWF Indonesia, Jakarta, Indonesia
[7]Coral Reef Alliance, Oakland, California
[8]Wildlife Conservation Society, Fiji Country Program, Suva, Fiji
[9]Cenderawasih Bay National Park Authority, Kementerian Lingkungan Hidup dan Kehutanan, Manokwari, West Papua, Indonesia
[10]Marine and Fisheries Directorate, WWF-Indonesia, Denpasar, Bali, Indonesia
[11]Unit Pelaksana Teknis Dinas, Kawasan Konservasi Perairan Daerah Raja Ampat, Raja Ampat, West Papua, Indonesia

Correspondence
Purwanto, University of Papua, Jl. Gunung Salju, Amban, Manokwari, West Papua, 98314, Indonesia.
Email: purwanto.marine@gmail.com

Dominic A. Andradi-Brown, Ocean Conservation, World Wildlife Fund, 1250 24th St., NW, Washington, DC, 20037.
Email: dominic.andradi-brown@wwfus.org

Abstract

The Bird's Head Seascape (BHS), Papua, Indonesia is located within the epicenter of global marine biodiversity and has been the focus of recent conservation efforts to protect marine resources. Here, we provide an overview of Marine Protected Areas (MPAs) progress in the BHS over the past decade, including establishment history, changes in management effectiveness and ecosystem health, as well as examining trends in tourism growth. While generally viewed as a conservation success story, we reflect on both successes and challenges in the BHS, identifying where we need to continue to improve and adapt in response to rapid economic and environmental change. As of 2020, BHS MPAs cover 5.1 million ha across 23 MPAs. As expected, management effectiveness is steadily increasing in BHS MPAs—although newer MPAs face

Purwanto and Dominic A. Andradi-Brown should be considered joint first authors.

substantial capacity gaps. Tourism is rapidly growing—with an almost 3,000% increase in tourist visits between 2007 and 2018. Overall, hard coral cover in monitored BHS MPAs remained stable at 33% from 2010 to 2019, although trends in reef fish biomass were more variable. Given continued conservation challenges in the region, BHS MPAs are successfully preventing biodiversity loss while providing ecosystem services for local communities.

KEYWORDS

coral reef, effectiveness, fish biomass, Indonesia, management, mangrove, Marine Protected Area, Raja Ampat, seagrass, West Papua

1 | INTRODUCTION

The Bird's Head Seascape (BHS) in West Papua and Papua provinces, Indonesia (Figure 1), is the global epicenter of marine biodiversity (Bowen, Rocha, Toonen, & Karl, 2013; Huffard et al., 2012; Huffard, Erdmann, & Gunawan, 2012; Renema et al., 2008; Veron et al., 2009), encompassing more than 2,500 islands spread across 225,000 km^2 (Ahmadia et al., 2017; Huffard, Erdmann, & Gunawan, 2012). The BHS supports 75% of known hard (scleractinian) coral species (DeVantier, Turak, & Allen, 2009; Veron et al., 2009; Wallace, Turak, & DeVantier,

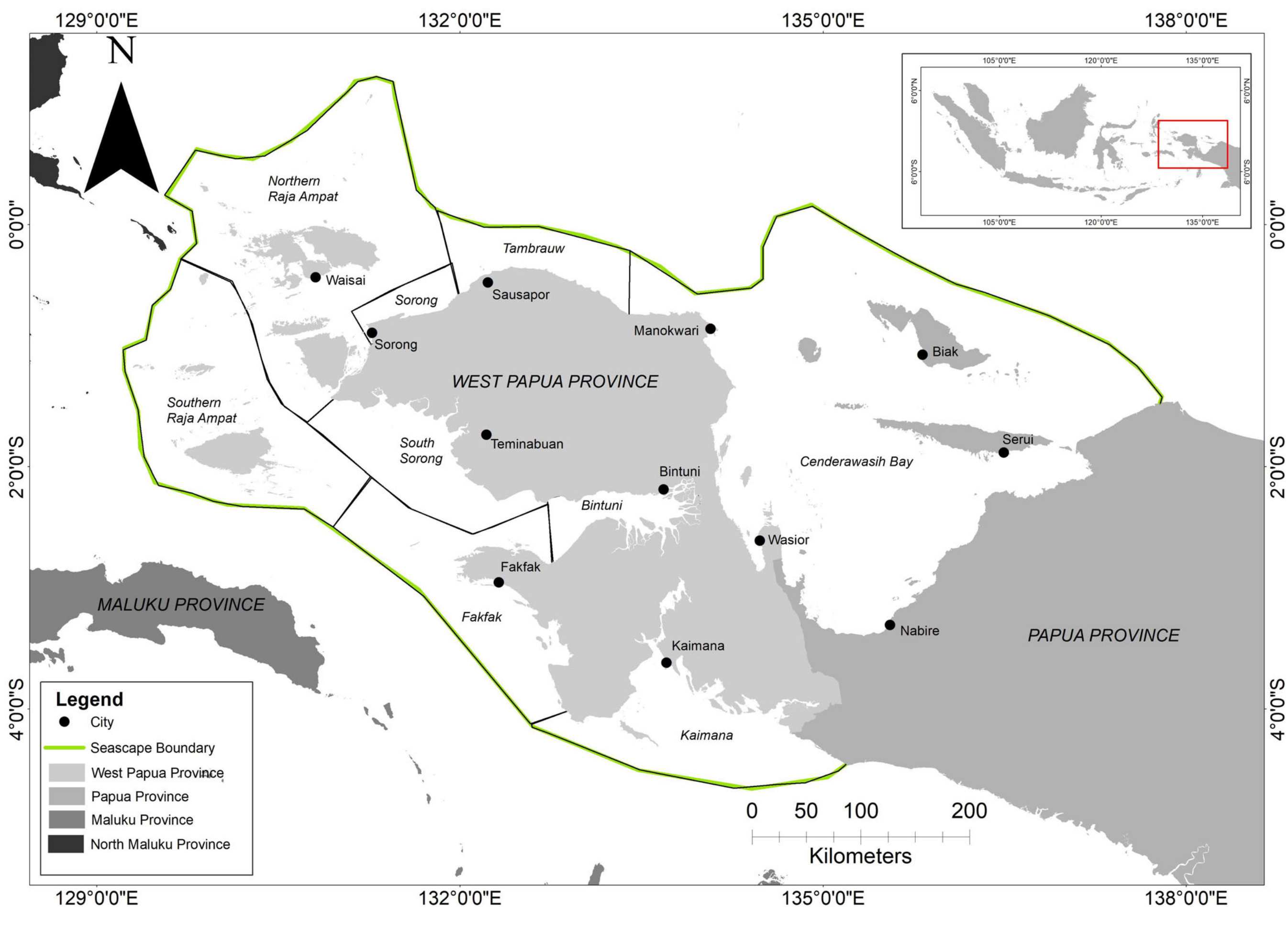

FIGURE 1 Political boundaries in the Bird's Head Seascape (BHS). Outer boundaries of the BHS were delineated based on biogeographic, oceanic, and genetic connectivity between reef areas, and share ecological and environmental characteristics (Green & Mous, 2008). The nine coastal sub-regions used for analysis are shown

2011), >1,600 reef fish species (Allen & Erdmann, 2009, 2012), and is host to some of the most extensive and diverse mangrove and seagrass ecosystems globally (Alongi, 2007; McKenzie, Coles, & Erftemeijer, 2006). Coastal ecosystems in the BHS also provide a wealth of ecosystem services for the culture, livelihoods, and food security of approximately 350,000 people in the region (Badan Pusat Statistik, 2010; Larsen, Leisher, Mangubhai, Muljadi, & Tapilatu, 2011).

BHS coastal ecosystems and the communities that depend on them are subject to multiple local and global threats (Mangubhai et al., 2012). Small-scale fisheries are under pressure from destructive fishing practices, overfishing, and habitat degradation and loss (Ainsworth, Pitcher, & Rotinsulu, 2008; Heazle & Butcher, 2007; Palomares, Heymans, & Pauly, 2007). Illegal hunting of threatened species such as sea turtles (Tapilatu, 2017) and sharks (Jaiteh et al., 2016) is still occurring. Corals have been threatened by outbreaks of corallivorous crown-of-thorns starfish (*Acanthaster planci*) (Salm, Petocz, & Soehartono, 1982) and localized bleaching events (Ahmadia et al., 2017; Mangubhai et al., 2012). Coastal degradation has also occurred, due to rapid coastal infrastructure development, in some instances failing to comply with environmental regulations (Indrawan et al., 2019). Many of these challenges are driven by larger social, political, and economic trends observed across eastern Indonesia (Indrawan et al., 2019), putting increasing pressure on marine resource extraction and ecosystem health. The BHS is at a crossroads, currently attempting to balance sustainable economic growth while maintaining environmental health.

Over the past three decades, the promulgation of environmental policies has led to changes in BHS governance and management of marine resources (Mangubhai et al., 2012), blending customary marine management with more contemporary forms of conservation. Indigenous Papuan communities historically have rights for fisheries under customary laws—known as *adat*—allowing them to manage their resources and maintain cultural practices (McLeod, Szuster, & Salm, 2009). Special autonomy was granted by the national government in 2001 to enable regency governments and the West Papua and Papua provincial governments to protect, manage, and exploit their natural resources—including fisheries and forests—in the interests of local communities (Donnelly, Neville, & Mous, 2003; McLeod et al., 2009; Wijayanto 2016). Additional institutionalized efforts for BHS marine conservation began in the 1990s with the identification of critical marine areas for protection and management initiated by non-government organizations (NGOs) alongside the Ministry of Environment and Forestry (MoEF). This led to the establishment of Sabuda Island and Tataruga Island Marine Protected Area (MPA) in Fakfak Regency in 1993 and Cenderawasih Bay National Park in 2002 (Ahmadia et al., 2017). This was followed by multiple regency governments initiating MPAs, including in Raja Ampat in 2001, Tambrauw in 2005, and Kaimana in 2006 (Mangubhai et al., 2012; Table 1). Indonesia's marine conservation areas have multiple legal foundations and management arrangements. The majority of BHS MPAs were established and gazetted "bottom up" through initial community customary (*adat*) declarations, then supported by regency or provincial regulations, before being reinforced by national recognition (Mangubhai et al., 2012). These MPAs have dual objectives of biodiversity conservation and local sustainable use—with zoning and management plans integrating traditional practices and involving communities in active MPA management. Therefore, each MPA has both no-take areas (where all extractive activity is prohibited) and sustainable use areas that promote the adoption of sustainable fisheries approaches by local communities while implementing some fisheries restrictions (e.g., fisheries vessel size and gear restrictions). National MPA declarations may be made under MoEF or the Ministry of Marine Affairs and Fisheries (MMAF), with MPAs managed by the central government, provincial government MMAF office, or MMAF–supported quasi-governmental management units. The majority of BHS MPAs are based on MMAF law and managed by the West Papua Provincial Government (Table 1). By 2012, the BHS MPA network had expanded to include 12 MPAs with a combined area of 3,594,702 ha (Mangubhai et al., 2012).

In 2014, there was a major change in Indonesia's local government natural resource laws concerning MPA governance (Law [UU] No. 23/2014). Prior to 2014, regency governments managed resources including forests, fisheries, and MPAs directly, but the new regulation shifted authority to provincial governments (Dirhamsyah, 2016). The 2014 law also changed marine jurisdiction, removing regency control of 0–4 NM coastal waters and placing jurisdiction for 0–12 NM with provincial governments (Dirhamsyah, 2016). These changes led to a transition period as provincial governments took over MPA management for previously regency-managed MPAs. While MPA management continued, management capacity was affected as provincial governments developed systems and technical expertise for these new responsibilities.

Since 2012, when the last BHS MPA review was published (Mangubhai et al., 2012), increasing conservation awareness and perceived benefits of MPAs has generated momentum for burgeoning conservation initiatives across the BHS, much of it driven by local communities. Here, we provide an overview of the progress and changes that have occurred in the BHS MPA network since 2012,

TABLE 1 Bird's Head Seascape marine protected areas (MPAs) and sub-regions used in this study

Sub-region/ MPA number	MPA overview: English name	Indonesian name	Area (ha)	No-take zone area (ha)	Management agency	MPA timeline (year): Initiation	Establishment	Zonation	MPA data collection: Ecological monitoring sites	Ecological monitoring years	World Bank Score Cards years
North Raja Ampat											
1	Ayau-Asia Islands	TWP Raja Ampat—Kepulauan Ayau-Asia	99,339	11,005	UPTD-BLUD, MMAF—West Papua Province	2001	2006	2012	18	2010, 2012, 2014, 2016, 2018	2012–2019
2	West Waigeo	SAP Waigeo Sebelah Barat	266,695	5,795	MMAF—National Government	2009	2009	2014	8	2012, 2014, 2016, 2018	2012–2019
3	Mayalibit Bay	TWP Raja Ampat—Teluk Mayalibit	49,451	14,684	UPTD-BLUD, MMAF—West Papua Province	2001	2006	2012	12	2012, 2014, 2016, 2018	2012–2019
4	Raja Ampat Islands	SAP Kepulauan Raja Ampat	60,002	15,208	MMAF—National Government	2009	2009	2014	3	2012, 2015, 2017, 2019	2019
5	Dampier Strait	TWP Raja Ampat—Selat Dampier	353,531	53,615	UPTD-BLUD, MMAF—West Papua Province	2001	2006	2012	15	2010, 2011, 2014, 2016, 2018	2012–2019
South Raja Ampat											
6	Fam Islands	TWP Raja Ampat—Kepulauan Fam	357,282	100,260	UPTD-BLUD, MMAF—West Papua Province	2015	2017	—	16	2012, 2014, 2015, 2016, 2017, 2019	2019
7	Kofiau and Boo Islands	TWP Raja Ampat—Kepulauan Kofiau dan Boo	149,208	15,955	UPTD-BLUD, MMAF—West Papua Province	2001	2006	2012	22	2011, 2013, 2014, 2016, 2018	2012–2019
8	North Misool	KKPD Misool Utara	311,064	*Not zoned*	Local community	2016	—	—	2	2012, 2015, 2017	2019
9	South East Misool	TWP Raja Ampat—Misool Timur Selatan	346,189	81,394	UPTD-BLUD, MMAF—West Papua Province	2001	2006	2012	25	2011, 2013, 2015, 2017, 2019	2012–2019
Tambrauw											
10	Jeen Womom	TP Jeen Womom	32,250	2,251	MMAF—West Papua Province	2005	2015	2017	—	—	2012–2019
Sorong											
11	Sorong	KKP Maksegara, Kabupaten Sorong	147,590	*Not zoned*	MMAF—West Papua Province	2018	—	—	—	—	—
South Sorong											
12	South Sorong	KKP Laut Seribu Satu Sungai Teo Enebikia, Sorong Selatan	338,000	*Not zoned*	MMAF—West Papua Province	2017	—	—	—	—	2019
Bintuni											
13	Bintuni Bay	CA Teluk Bintuni	135,102	*Not zoned*	MoEF—National Government	1999	2014	—	—	—	—

TABLE 1 (Continued)

	MPA overview					MPA timeline (year)			MPA data collection		
Sub-region/ MPA number	English name	Indonesian name	Area (ha)	No-take zone area (ha)	Management agency	Initiation	Establishment	Zonation	Ecological monitoring sites	Ecological monitoring years	World Bank Score Cards years
Fakfak											
14	Sabuda Island and Tataruga Island	CAL Pulau Sabuda dan Pulau Tataruga	5,000	5,000	MoEF—National Government	1993	1993	1993	—	—	—
15	Berau Bay	TP Teluk Berau	101,138	3,440	MMAF—West Papua Province	2017	2017	—	—	—	2019[a]
16	Nusalasi Van Den Bosch Bay	TP Teluk Nusalasi—Van Den Bosch	253,961	29,788	MMAF—West Papua Province	2017	2017		8	2012, 2015, 2019	
Kaimana											
17	Arguni Bay	TWP Kaimana—Teluk Arguni	35,712	8,224	MMAF—West Papua Province	2006	2008	2018	—	—	2012–2019[b]
18	Buruway	TWP Kaimana—Buruway	233,211	47,925	MMAF—West Papua Province	2006	2008	2018	20	2012, 2015, 2019	
19	Kaimana City	TWP Kaimana—Kota Kaimana	122,655	11,222	MMAF—West Papua Province	2006	2008	2018	24	2013, 2016, 2019	
20	Etna Yamor	TWP Kaimana—Etna Yamor	111,616	14,606	MMAF—West Papua Province	2006	2008	2018	—	—	
Cenderawasih Bay											
21	Padaido Islands	TWP Kepulauan Padaido	183,000	3,925	MMAF—Papua Province	1997	2009	2014	—	—	—
22	Cenderawasih Bay National Park	Taman Nasional Teluk Cenderawasih	1,453,000	114,545	MoEF—National Government	1998	2002	2002	29	2011, 2016, 2018	2012–2019
23	Biak Numfor	KKP Kabupaten Biak Numfor	24,910	1,245	MMAF—Papua Province	2009	2009	2009	—	—	—

Note: Sub-regions represent regencies with the exception of north and south Raja Ampat (two MPA management units comprising Raja Ampat regency) and Cenderawasih Bay which spans Manokwari, South Manokwari, Kepulauan Yapen, Waropen, Mamberamo Raya, Biak Numfor, Supiori, Teluk Wondama, and Nabire regencies. MPA timelines follow the definitions for initiation, establishment, and zonation from the Technical Guidelines for Evaluating the Management Effectiveness of Aquatic, Coasts and Small Islands Conservation Areas (E-KKP3K). Spatial analysis for MPA extent was conducted based on area and critical habitats present within MPA outer boundaries. See Table S1 for expanded MPA table with more details including other names each MPA is known by and MPA initiation, establishment, and zonation provincial and national government decrees. Indonesian MPA types include: Cagar Alam (CA; Nature Sanctuary), Cagar Alam Laut (CAL; Marine Nature Sanctuary), Suaka Alam Perairan (SAP; Marine Sanctuary), Kawasan Konservasi Perairan (KKP; Marine Protected Area), Kawasan Konservasi Perairan Daerah (KKPD; Regional Marine Protected Area), Taman Pesisir (TP; Coastal Park), Taman Wisata Perairan (TWP; Water Park). MPA management agencies include: the Ministry of Marine Affairs and Fisheries (MMAF) or the Ministry of Forestry and Environment (MoEF) at the provincial or national level, or the Regional Public Service Body (UPTD-BLUD). West Papua Provincial MPAs are managed by the Maritime and Fisheries Service, West Papua Province (Dinas Kelautan dan Perikanan). Ecological monitoring sites represent the number of unique sites surveyed.

[a]Single joint assessment for both Berau Bay and Nusalasi Van Den Bosch Bay.

[b]Single joint assessment conducted annually for the combined Kaimana MPA network.

focusing on changes in: (a) MPA extent, coverage of critical habitats, and establishment status; (b) management effectiveness and compliance; (c) tourism; and (d) ecosystem health. We highlight lessons from the BHS that have led to conservation success. We also provide an overview of the opportunities and challenges, recognizing that there are still ongoing management gaps as well as broader social, development, and environmental changes influencing conservation outcomes.

2 | METHODS

2.1 | Study area

We divided the BHS into nine sub-regions for analyses, which largely represent regencies, with the exception of Raja Ampat and Cenderawasih Bay (Figure 1; Table 1). Six of the sub-regions align with existing regencies: Tambrauw, Sorong, South Sorong, Bintuni, Fakfak, and Kaimana. Raja Ampat Regency was divided into North and South Raja Ampat, reflecting the two distinct management units used by the management authority for MPAs within this regency. Cenderawasih Bay is a geographically large area, spanning nine regencies in West Papua and Papua provinces and containing three MPAs (Table 1), including Cenderawasih Bay National Park, which spans three regencies: Teluk Wondama, South Manokwari, and Nabire. With the exception of the National Park—which has extensive monitoring—very little monitoring data are available for the other MPAs within Cenderawasih Bay (Table 1). Therefore, we group Cenderawasih Bay together as a single BHS sub-region within this assessment.

2.2 | MPA extent, critical habitat coverage, and establishment status

MPA boundaries and zonation were sourced from the respective MPA management authorities in January 2020. The Indonesian Geospatial Information Agency (*Badan Informasi Geospasial*; BIG) national coral reef, mangrove forest, and seagrass bed spatial layers were used to quantify critical habitat coverage in the BHS. Changes in mangrove extent was calculated for 1996–2016 using Global Mangrove Watch spatial layers (Bunting et al., 2018). These layers represent the most consistent and accurate mangrove time-series available and are based on remote sensed data (Bunting et al., 2018). Critical habitat inclusion within MPAs was calculated based on the outer boundaries for all MPAs, while analyses of critical habitats coverage under differing protection levels (no-take vs. sustainable use areas) was derived only from those MPAs with zonation (Table 1).

MPA establishment status was assessed following the MMAF "Technical Guidelines for Evaluating the Management Effectiveness of Aquatic, Coasts and Small Islands Conservation Areas"—known by the Indonesian acronym E-KKP3K (KKJI, 2012). This tool consists of questions for MPA managers that identify the establishment status of the MPA based on activities completed, resources available, and different levels of government approval. Color bands are used to indicate MPA progress, with red for "under initiation" or "initiated," yellow for "established," green for "minimally managed," blue for "optimally managed," and gold for "long-term self-reliant" MPAs. E-KKP3K evaluations are typically conducted at an annual workshop, bringing together MPA management staff from the region. E-KKP3K assessments for MMAF MPAs represent the official assessments conducted by their respective MPA management authority, while assessments for MoEF MPAs represent unofficial assessments conducted by NGO staff in partnership with the respective MPA management authority.

2.3 | Management effectiveness and compliance assessments

BHS MPA management effectiveness was measured using World Bank Score Cards (WBSC; Staub & Hatziolos, 2004). WBSC are self-assessments based on 34 questions assessed by MPA managers and follow a standardized framework aligned with the Management Effectiveness Tracker Tool (Stolton et al., 2007; Stolton, Hockings, Dudley, Mackinnon, & Whitten, 2003). Each WBSC question is multiple choice, with between 0 (low effectiveness) and 3 (high effectiveness) points available, and additional points for key additional factors. Questions are framed around six areas on MPA context, planning, inputs, process, outputs, and outcomes (Staub & Hatziolos, 2004). Scores are converted to percentages, with higher scores reflecting greater management effectiveness. Annual assessments were conducted between 2012–2019 in MPAs across five BHS sub-regions, and assessments were conducted in 2019 in MPAs in seven BHS sub-regions (Table 1). Assessments were conducted at annual workshops alongside E-KKP3K assessments.

Management authorities for established BHS MPAs are required to conduct regular patrolling activities. We analyzed patrol records from the North Raja Ampat MPA management authority for 2010–2016, and from the South Raja Ampat MPA management authority for 2015–2016. During patrols, MPA management staff and The Nature Conservancy or Conservation International staff travel regular routes through the MPAs and observe the locations of resource users within zones, approaching vessels to identify activities being conducted. These patrols were conducted within all established MPAs (Table 1), although at variable frequencies. The numbers of MPA patrols for North Raja Ampat annually were 29 (2010), 130 (2011), 119 (2012), 402 (2013), 901 (2014), 450 (2015), and 668 (2016), and for South Raja Ampat were 53 (2015) and 171 (2016). From 2011–2014 in South Raja Ampat, as part of supporting the establishment of the MPA management authority, The Nature Conservancy conducted resource use surveys in a highly similar method to the patrols in Kofiau and Boo Islands MPA and South East Misool MPA (Wiadnya et al., 2006). The numbers of surveys for South Raja Ampat were 31 (2011), 55 (2012), 101 (2013), and 10 (2014). We filtered records to identify the percentage of patrols per year that identified (a) fishing activities in no-take zones and (b) fishers using or possessing destructive fishing gears (blast and cyanide fishing) on their vessels.

2.4 | Tourism

The Raja Ampat government provided records of 2007–2019 annual tourist entry permits issued for all Raja Ampat MPAs (North and South Raja Ampat combined). We also obtained 2007–2018 annual tourist entry permit numbers for Cenderawasih Bay National Park from the park management authority. Tourist entry numbers were broken down by domestic and international tourists, as these attract different permit fees. Scuba diving is a major tourist attraction in the region, and liveaboard boats for scuba diving are required to register with the respective regency government. We sourced data on the number of liveaboard boats registered in Raja Ampat Regency (North and South Raja Ampat combined) annually from 2010 to 2019 from the harbormaster at Waisai Port.

2.5 | Ecosystem health

Ecological monitoring data were collected from 202 sites in 13 MPAs representing five BHS sub-regions between 2010 and 2019 (Table 1). Ecological monitoring in the BHS MPAs followed standardized protocols (Ahmadia, Wilson, & Green, 2013; Wilson & Green, 2009). All divers undertook benthic or fish identification training before conducting surveys and conducted practice transects, including estimating fish lengths. Hard coral cover was collected at each site using point intercept transects, recording benthic cover at 0.5 m intervals along three 50 m transects separated by 10 m intervals, and laid on the reef slope at 8–12 m depth. Fish species' abundance and length estimates were assessed by underwater visual census following Ahmadia et al. (2013), using five 50 m transects per site at 8–12 m depth and separated by 10 m intervals. Fish species recorded were families/subfamilies Acanthuridae, Carangidae, Carcharinidae, Dasyatidae, Haemulidae, Lethrinidae, Lutjanidae, Scaridae, Scrombidae, Serranidae, Siganidae, and the species *Cheilinus undulatus*. Transects were surveyed using two survey widths depending on fish length, with two fish observers simultaneously swimming the transect. Fish estimated to be >10 cm and <35 cm length were counted using a 5 m transect width, while fish estimated to be ≥35 cm were counted on a 20 m transect width. Fish lengths were converted to biomass using standardized fish length-weight conversion coefficients from MERMAID (www.datamermaid.org) based on FishBase (Froese & Pauly, 2019). Arithmetic mean percentage hard coral cover, total fish biomass (all recorded species), high–value fisheries species (families Serranidae, Lutjanidae, Lethrinidae, and Haemulidae), and herbivorous fish biomass (families/subfamilies Acanthuridae, Scaridae, and Siganidae) were calculated to determine current reef status and trends within each MPA and sub-region.

As ecological field monitoring was typically conducted on a two-year cycle after 2013, we grouped monitoring data into four time periods: (a) 2010–2013 (baseline), (b) 2014–2015, (c) 2016–2017, and (d) 2018–2019. Within the 202 ecological monitoring sites, 119 sites were surveyed in all four time periods, while 83 sites were surveyed at baseline and two subsequent periods (Table 1). Sites were averaged together by sub-region for trend analyses.

2.6 | Data analyses

All spatial data analyses were conducted in ArcGIS (ESRI, 2020). To identify trends in management effectiveness, compliance, and tourism numbers we used a Mann-Kendall trend test fitted using the "mk.test" function in the trend package (Pohlert, 2020) in R (R Core Team, 2020). Mann-Kendall trend tests are a non-parametric method to detect monotonic trends within a time series. Trends in ecosystem health were analyzed by zone using a linear mixed–effect model with site as a random effect to account for repeat surveys. The model had the form ecosystem health indicator ~ survey year + (1|site). To meet model assumptions, percentage hard coral cover was arcsine transformed, and fish biomass values were log + 1 transformed prior to analysis. Models were fitted and significance assessed using the "lmer" function from the lmerTest package (Kuznetsova, Brockhoff, & Christensen, 2017), which builds on the lme4 package (Bates, Mächler, Bolker, & Walker, 2015) in R.

We used Satterthwaite approximations to generate degrees of freedom and p-values, which is a preferred method for evaluating significance from mixed–effect models because of low Type I error rates (Luke, 2017). All statistical results are reported as mean ± 95% confidence intervals unless otherwise stated.

3 | RESULTS

3.1 | MPA extent, status and critical habitat coverage

Over the past two decades MPA numbers and extent have grown substantially in the BHS—from three MPAs in 2000 to 23 current MPAs covering 5,169,905 ha (Figure 2a; Tables 1 and S1). After the first MPAs were initiated in the 1990s, there was rapid MPA development in Raja Ampat and Kaimana, with seven of the nine current MPAs in Raja Ampat and two in Kaimana initiated and established between 2001 and 2009 (Table 1). More recently, from 2015 to the present, a second wave of MPA establishment occurred—expanding the BHS MPA network into sub-regions previously without MPAs (Table 1). This second wave was driven by local communities proposing new MPAs—such as in Fam Islands, North Misool, Fakfak, Bintuni, and South Sorong—with the support of NGOs and the provincial government. Therefore, the current BHS MPA network consists of a patchwork of MPAs at various stages of establishment

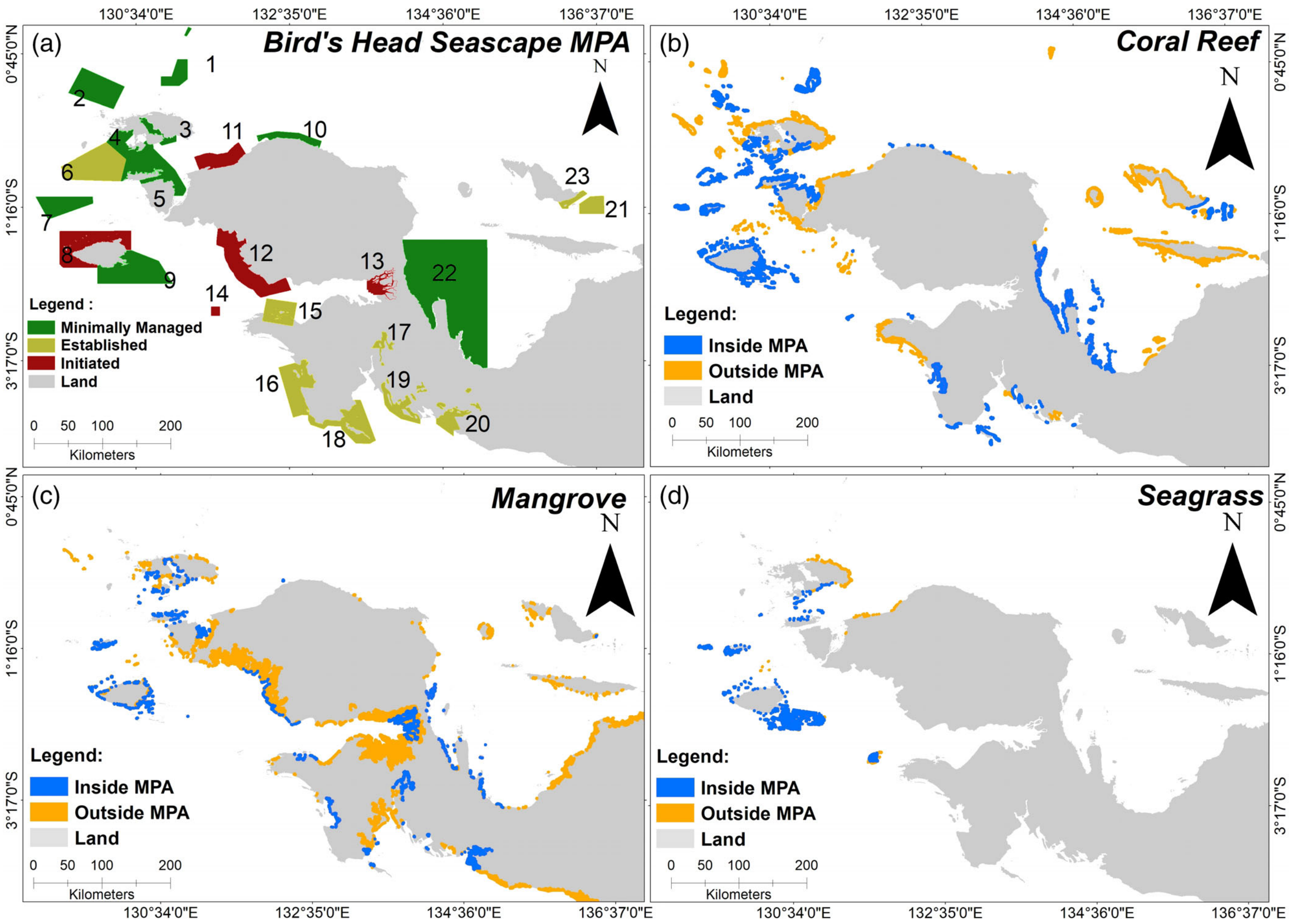

FIGURE 2 (a) Marine protected areas within the Bird's Head Seascape colored by 2019 establishment status based on MMAF's Technical Guidelines for Evaluating the Management Effectiveness of Aquatic, Coasts and Small Islands Conservation Areas (E-KKP3K). MPAs are numbered as in Table 1: (1) Ayau-Asia Islands, (2) West Waigeo, (3) Mayalibit Bay, (4) Raja Ampat Islands, (5) Dampier Strait, (6) Fam Islands, (7) Kofiau and Boo Islands, (8) North Misool, (9) South East Misool, (10) Jeen Womom, (11) Sorong, (12) South Sorong, (13) Bintuni Bay, (14) Sabuda Island and Tataruga Island, (15) Berau Bay, (16) Nusalasi Van Den Bosch Bay, (17) Arguni Bay, (18) Buruway, (19) Kaimana City, (20) Etna Yamor, (21) Padaido Islands, (22) Cenderawasih Bay National Park, and (23) Biak Numfor. Critical habitat extent is shown for (b) coral reef, (c) mangrove forest, and (d) seagrass bed extent. Habitat distribution data is colored based on protection status and has been buffered by 2 km for display. Habitat distribution data are official Indonesian Geospatial Information Agency (Badan Informasi Geospasial) data layers

and implementation. Eight MPAs meet the E-KKP3K criteria for being "minimally managed," six are "established," four are "initiated," and five have not yet been assessed by E-KKP3K (Tables 1 and S1). No BHS MPAs have yet met the E-KKP3K criteria for being "optimally managed" or for being "long-term self-reliant MPAs." Individual MPAs range from 5,000 to 1,453,000 ha in area (Table 1), with 535,087 ha of no-take areas within the BHS (Table S2). Raja Ampat regency has nine MPAs—the most of any regency (Table 1).

The BHS contains 159,087 ha of coral reefs, 36,231 ha of mangroves, and 15,863 ha of seagrass (Table S2), of which 21% of coral reefs (Figure 2b), 8% of mangrove forests (Figure 2c), and 2% of mapped seagrasses are currently located within MPAs (Figure 2d). Within MPAs, 4% of coral reefs, <1% of mangroves, and <1% of mapped seagrass are located within no-take zones, with the rest in sustainable use zones (Table S3). The Kaimana subregion encompasses 78% of all mangroves within the entire BHS—although only 5% of these are within MPAs and this region had the greatest mangrove loss from 1996 to 2016 at 315 ha (Tables S2 and S3).

3.2 | Management effectiveness and compliance

WBSC assessments indicated that in 2019 the mean BHS MPA management effectiveness was 67 ± 15%. Based on all MPAs that were assessed in 2019, North Raja Ampat had the greatest management effectiveness (86 ± 3%), while the single assessed MPA in South Sorong had the lowest (10%; Table S2). Across all sub-regions, MPAs that were annually assessed from 2012–2019 showed increases in World Bank Scores ($p < .05$ for all; Figure 3a). The greatest increase in management effectiveness over the 2012–2019 period occurred for Tambrauw, which increased from 46% to 73% (Figure 3a). While overall management effectiveness increased, several MPAs experienced some short-term declines in scores during the time series. For example, Cenderawasih increased in management effectiveness from 2012 to reach 66% in 2015, before decreasing to 60% in 2016, and then increasing to 79% in 2017 (Figure 4a).

Based on data compiled from patrols, patterns in compliance were more variable, although compliance generally increased. Fewer fishers were observed fishing in no-take zones and there was lower prevalence of destructive fishing gears observed on vessels in 2019 compared to 2010 for North Raja Ampat (Figure 3b,c). For example, illegal fishing within no-take zones in North Raja Ampat declined ($S = -15$, $p = .036$), with 34% of patrols in North Raja Ampat in 2010 identifying fishing in no-take areas, dropping to 2% in 2014 and remaining stable until 2016 (Figure 3b). By contrast, 16% of patrols in South Raja Ampat in 2011 identified illegal fishing within no-take zones, which declined to 2% in 2015, before rising to 18% in 2016 (Figure 3b). No destructive fishing gears were observed on vessels anywhere within the MPAs by patrols in North Raja Ampat in 2010, though 7% of patrols reported them in 2011, which declined to 1% by 2013 before remaining stable (Figure 3c). For South Raja Ampat, 31% of patrols in 2011 identified destructive fishing gears on vessels within the MPAs, which declined to 5% in 2013 and remained <5% until 2016 (Figure 4c).

3.3 | Tourism

The number of tourists has rapidly increased within the BHS MPA network, from 1,098 registered tourists in 2007 to 33,285 in 2018 for North and South Raja Ampat MPAs and Cenderawasih Bay National Park, representing a 2,931% increase. Across these regions, 88% of tourists were international in 2007 compared to 79% in 2019. The greatest absolute increase was in international visitors to Raja Ampat, which increased from 932 in 2007 to 24,131 in 2019—representing a 2,489% growth (Figure 4a). Domestic Raja Ampat tourist numbers, however, increased at a higher growth rate—8,761%—from 66 in 2007 to a peak of 5,848 in 2018, before dropping slightly to 3,056 in 2019 (Figure 4a). While Cenderawasih Bay National Park has lower tourist numbers than Raja Ampat, it has also experienced rapid growth, from 100 overall registered tourists in 2007 to a peak of 5,708 in 2015—representing a 5,608% increase—before declining to 4,339 in 2018 (Figure 4a). Registered scuba diving liveaboard vessels have also increased in Raja Ampat Regency ($S = 39$, $p < .001$), from seven in 2010 to 30 in 2019 (Figure 4b); these numbers are now capped at 30 by local decree.

3.4 | Trends in ecosystem health

Average hard coral cover was stable seascape–wide at 32.9 ± 2.6% for 2018–2019 compared to 30.1 ± 2.1% during 2010–2013. Cenderawasih Bay had the highest current hard coral cover at 45.5 ± 6.3%, and Kaimana the lowest at 18.7 ± 4.7% (Table S2) where more non-coral ecosystems, including mangroves and large estuarine systems, are encompassed by the MPA. Within sub-regions, average hard coral cover increased in sustainable use zones within South Raja Ampat from 31.2 ± 4.3% in 2010–2013 to 39.0 ± 5.2% (Figure 5a; Table S4). All other sustainable fishing zones or no-take zones within

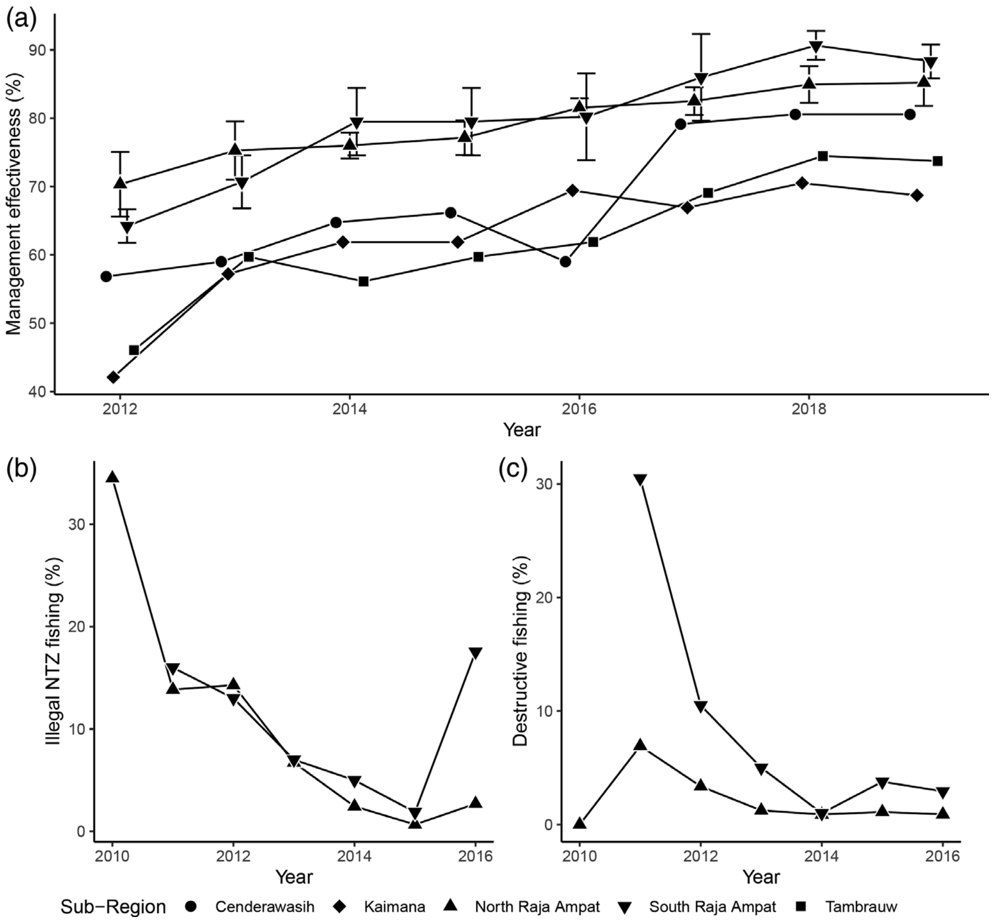

FIGURE 3 Changes in (a) Marine protected area management effectiveness, (b) illegal fishing in no-take zones (NTZ), and (c) destructive fishing gear use within the Bird's Head Seascape. (a) Management effectiveness is shown only for MPAs that have 2012–2019 time series available (Table 1). Where multiple MPAs within a sub-region have data, each MPA is treated as a replicate—that is, four North Raja Ampat MPAs, two South Raja Ampat MPAs, and single MPAs for Tambrauw and Cenderawasih Bay. Kaimana represents an aggregate score across all MPAs in the Kaimana MPA network as these have shared management and were assessed as if they were a single MPA. Mann–Kendall trend tests were used to assess significance: Cenderawasih ($S = 21$, $p = .008$), Kaimana ($S = 21$, $p = .013$), North Raja Ampat ($S = 28$, $p < .001$), South Raja Ampat ($S = 25$, $p = .002$), and Tambrauw ($S = 23$, $p = .006$). (b) and (c) show compliance from North and South Raja Ampat sub-regions. Compliance was measured as the percentage of patrols per year that recorded (b) fishers illegally fishing within no-take areas and (c) destructive fishing gears on vessels within the MPA boundaries. Error bars represent 95% Confidence Intervals above and below the mean

sub-regions had stable hard coral cover across the time series (Figure 5a,b; Table S4).

Total fish biomass declined 24% from 824 ± 388 kg/ha in 2010–2013 to 626 ± 168 kg/ha in 2018–2019. This seascape-wide decline was mostly driven by Kaimana total fish biomass, which declined by 92% in no-take zones ($4{,}667 \pm 4{,}446$ kg/ha to 353 ± 172 kg/ha; Figure 5d) and 78% in sustainable use zones (926 ± 365 kg/ha to 200 ± 78 kg/ha) from 2010–2013 to 2018–2019 (Figure 5c). However, Kaimana fish biomass had the greatest variability of any sub-region surveyed (Figure 5). Increases in fish biomass were recorded in MPAs within two sub-regions from 2010–2013 to 2018–2019 (Table S4). In North Raja Ampat total fish biomass increased 29% in no-take zones (585 ± 439 kg/ha to 753 ± 248 kg/ha; Figure 5d) and 218% in sustainable use zones (517 ± 212 kg/ha to $1{,}642 \pm 1{,}117$ kg/ha; Figure 5c). In South Raja Ampat fish biomass increased 71% in sustainable fishing zones (283 ± 100 kg/ha to 485 ± 165 kg/ha). Total fish biomass was stable across the timeseries for Cenderawasih and Fakfak.

For most sub-regions high-value fisheries species and herbivorous fish species follow the trends illustrated by total fish biomass. For example, biomass declines are recorded in both zone types for high-value fisheries species and herbivorous fish species in Kaimana (Figure 5e–h; Table S4). North Raja Ampat shows increases in both zone types for both high-value fisheries species and herbivorous fish species, while South Raja Ampat shows increases in fish biomass for sustainable

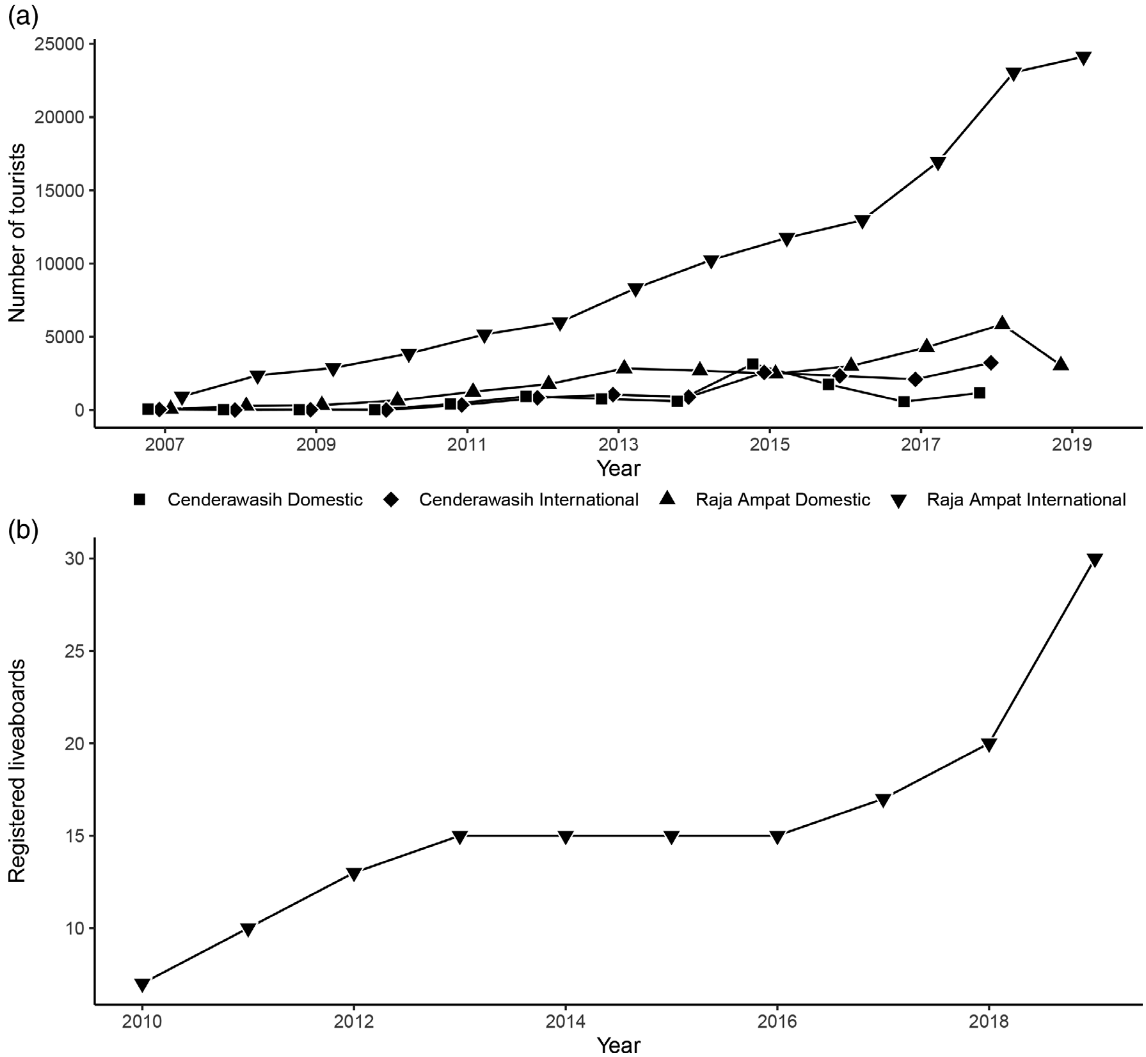

FIGURE 4 Tourism trends in the Bird's Head Seascape. (a) Domestic and international tourist numbers paying MPA entry fees for Raja Ampat (combination of all North and South Raja Ampat sub-region MPAs) and Cenderawasih (data only from Cenderawasih National Park). Mann–Kendall trend tests indicate tourist numbers increased across all groups: Cenderawasih domestic ($S = 34$, $p = .024$), Cenderawasih international ($S = 50$, $p < .001$), Raja Ampat domestic ($S = 68$, $p < .001$), and Raja Ampat international ($S = 78$, $p < .001$). (b) Officially registered liveaboard scuba diving vessels issued permits to operate in Raja Ampat by the harbormaster at the Port of Waisai, Raja Ampat Regency. Mann–Kendall trend test indicates the number of liveaboards increased through time ($S = 39$, $p < .001$)

fishing zones only (Figure 5e–h; Table S4). Interestingly, however, while Cenderawasih showed stable total fish biomass (Figure 5c,d), it had diverging results for the fish sub-groups. High-value fisheries species biomass declined 32% in use zones (137 ± 63 kg/ha in 2011 to 93 ± 105 kg/ha in 2018; Figure 3e), while herbivorous fish biomass increased 241% in no-take zones (91 ± 71 vs. 310 ± 188 kg/ha) and increased 157% in use zones (79 ± 52 vs. 203 ± 78 kg/ha) in Cenderawasih (Figure 5g,h).

4 | DISCUSSION

The establishment and management of the MPA network over the past two decades in the BHS has generally been successful, as shown by the levels of critical habitats protected, demonstrable ecological outcomes, increasing management capacity, and the inclusion of local communities in the establishment and co-management of MPAs in the region. While recognizing that many challenges still need to be addressed, overall lessons can be learned that can help inform conservation initiatives moving forward in the BHS and elsewhere.

4.1 | MPA network establishment and expansion

As of 2020, 23 MPAs in the BHS cover 5.1 million ha, with >1.5 million ha of this coverage achieved since

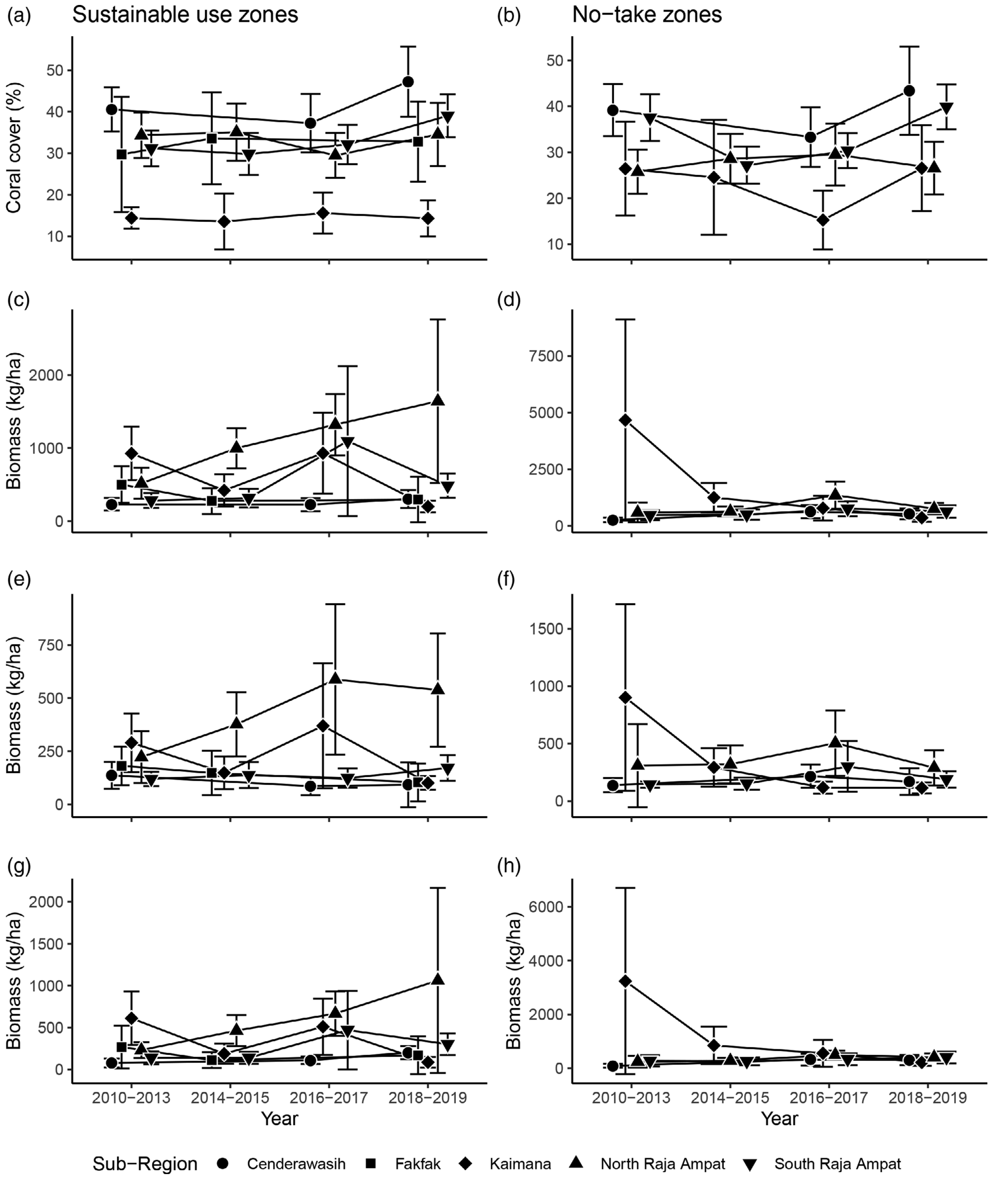

FIGURE 5 Ecosystem health trends in the Bird's Head Seascape marine protected area network for sustainable use zones and no-take zones. Figure shows hard coral cover in (a) sustainable use zones and (b) no-take zones; total fish biomass in (c) use zones and (d) no-take zones; high-value fisheries species in (e) use zones and (f) no-take zones; and herbivorous fish biomass in (g) use zones and (h) no-take zones. Error bars represent 95% confidence intervals above and below the mean. Table S5 contains statistical analyses for the significance of trends shown

2012. This momentum was largely driven by: (i) observed success of the earlier BHS MPAs generating interest from communities, funders, and other stakeholders; and (ii) motivation by the government to contribute towards Indonesia's national policy target of 20 million ha of MPAs by 2020. This has catalyzed more than USD 100 million invested in the region by philanthropic and public funders, including a dedicated conservation trust fund—the Blue Abadi Fund—to provide long-term steady financing for the MPA network and local conservation groups (Text S1). While the post–2012 rapid MPA expansion is encouraging, MPA initiation is only the first step. Some BHS MPAs have taken over a decade to reach E-KKP3K "minimally managed" status, and none have yet reached "optimally managed" status. BHS MPAs are at different steps on the establishment path from "initiation" to becoming "long-term self-reliant"—there is still much progress to be made to ensure that these MPAs deliver conservation outcomes.

4.2 | Trends in MPA management

Management effectiveness steadily increased for the nine MPAs that were assessed through time. Management performance increased consistently year to year in MPAs in Raja Ampat and Kaimana, which have received the most investment in training and capacity enhancement from NGOs and government. Cenderawasih Bay management effectiveness also increased, except from 2015–2016, where it decreased from 66% to 60%. As WBSC assessments are self-assessments conducted by MPA managers, slight variation is expected between years caused by changes in the staff evaluators. However, there was a 30% reduction in Cenderawasih Bay's annual management budget during this time frame that likely led to a decline. This budget reduction led to the Cenderawasih Bay National Park management authority reducing patrolling and enforcement activities as well as suspending some community engagement programs, although all management authority staff were retained. The 2014 transfer of MMAF MPA management authority from regency to the provincial level caused few detectable effects in WBSC despite significant staffing changes for many MPAs. Raja Ampat regency has developed a unique co-management structure—the Regional Public Service Body (Unit Pelaksana Teknis Daerah-Badan Layanan Umum Daerah; UPTD-BLUD)—which helped weather the transition in authority. The UPTD-BLUD is a quasi-government structure that supports the blending of government funding allocations with MPA revenues (such as tourism entry fees) and external fund sources (such as philanthropic and Blue Abadi Fund grants) into a consolidated local budget. It supports improved management by accommodating non-government expertise in staffing and governance structures, with approximately 140 local community members employed by the UPTD-BLUD in various capacities, including MPA patrolling. Raja Ampat's UPTD-BLUD continued to work through the transition period with minimal disruption with oversight successfully transitioned from regency to provincial government with the UPTD-BLUD staffing structure intact.

MPAs with management effectiveness assessments available from 2012 to 2019 are the older, more actively managed MPAs, thus are not representative of all 23 MPAs. Recent 2019 management effectiveness assessments for newer MPAs show they need to build management capacity (Table S1). For example, many of these MPAs do not have sufficient staff, equipment, and budget to conduct patrolling activities or community engagement. While potential bias exists in self-assessments for MPA management (e.g., Cook, Carter, & Hockings, 2014), the consistency and longevity of these assessments provide confidence in tracking changes to management. A focus on effective management must not get lost amidst MPA expansion, as building effectiveness is essential for achieving MPAs outcomes (Adams, Iacona, & Possingham, 2019; Kuempel, Adams, Possingham, & Bode, 2018; Gill et al., 2017).

4.3 | Managing tourism

Tourism has rapidly expanded in the BHS over the past decade (Figure 4a). Much of it is attributed to tourists visiting the MPAs. For example, whale shark tourism within Cenderawasih Bay National Park was estimated to bring USD 10.54 million into the Papuan economy in 2015 (Anna & Saputra, 2017). International and domestic tourists are driving demand for facilities such as liveaboard dive boats, resorts, and home stays, as well as broader infrastructure needed to support tourism. With tourism comes substantial revenue for the local economy (Atmodjo, Lamers, & Mol, 2017); however, there is increasing pressure on coastal ecosystems including: (a) high volumes of divers on coral reefs that can cause physical reef damage; (b) anchor damage from boats mooring over sensitive habitats; (c) increased fisheries demand for consumption by tourists; and (d) pollution and nutrient releases caused lack of infrastructure and poor waste management practices (Papilaya, Boli, & Nikijuluw, 2019).

Local government is faced with the responsibilities growing tourism brings, for example, how to take advantage of tourism and ensure equitable distribution of benefits while mitigating negative ecological and social impacts (Text S2). Rapid social change has also accompanied the growth of the sector, bringing new actors into local economies but also highlighting the extent of social needs, including education and health services. The extent communities perceive they benefit from tourism growth can influence their support for the MPAs, and their active participation in management. An ad-hoc "patchwork" of approaches to managing marine tourism emerged from the first BHS MPAs, largely led by communities, pioneer operators, and regency governments. This has evolved to a more strategic and integrated management approach (Atmodjo, Lamers, & Mol, 2019), although it must continue to adapt with policy changes and the influx of tourism. Despite tourism's inherent challenges, it remains more sustainable and socially acceptable than the industrial mining, forestry, and fisheries plans for Papua widely espoused by the government two decades ago (Fatem et al., 2020; Mangubhai et al., 2012).

During 2020, MPA tourism in the BHS was severely impacted by the coronavirus (COVID-19) pandemic like many MPAs globally (Phua et al., 2021). COVID-19 has led to tourism collapse in Raja Ampat—impacting many livelihoods and businesses (Awaludinnoer et al., 2021). Ferry and flight frequency across the region were reduced. This has increased isolation for MPA residents in more remote areas of the BHS and prevented them from selling fisheries catches (Awaludinnoer et al., 2021). The pandemic effects have impacted UPTD-BLUD, which is heavily dependent on tourism fees to fund management activities in Raja Ampat (see Text S2)—although this has been partially subsidized by an emergency grant from a private foundation to maintain activities during the pandemic (Awaludinnoer et al., 2021). However, management activities have been reduced and UPTD-BLUD has been required to make staff reductions. A new strategy is under development to set BHS MPAs on a more sustainable path post-pandemic. This new strategy includes financial diversification for management activities funding, and a significant focus on increasing sustainability and improving management of tourism-associated development as tourism recovers from the pandemic (Awaludinnoer et al., 2021).

4.4 | Critical habitat protection and ecosystem health

BHS MPA network expansion has increased protection for critical coastal ecosystems—with 21% of coral reefs, 8% of mangrove forests, and 2% of seagrasses within the BHS now located within MPAs. Despite climate change causing substantial global coral reef declines during 2014–2017 (Eakin, Sweatman, & Brainard, 2019), hard coral cover remained stable across the BHS from 2013 to 2019 (Figure 5a,b). While some localized coral bleaching occurred during 2016 in Cenderawasih Bay National Park (Groff et al., 2016), this did not cause widespread mortality and coral cover remained stable. Mangrove forests in the BHS have also broadly remained stable, in stark contrast to rapid rates of national and global losses (Friess et al., 2019). When much of the globe is seeing declines in critical habitats, maintaining stability for these ecosystems should be viewed as a success, particularly as these ecosystems were generally in good condition to begin with.

Overall reef fish biomass declined in BHS MPAs from 2010 to 2019, although this decline masks highly variable trends between sub-regions, with most MPAs actually stable or increasing in fish biomass. Much of the overall decline in BHS fish biomass was driven by Kaimana MPAs, which had exceptionally high fish biomass in baseline surveys (Text S3). In both North and South Raja Ampat MPAs, fish biomass increased within sustainable use zones, suggesting that these MPAs are balancing sustainable fishing with biodiversity conservation. Fish biomass trends are not representative of all BHS MPAs, as MPAs with established monitoring programs have greater management capacity, although our results broadly reflect other recent BHS reef fish studies (e.g., Mudjirahayu, Rembet, Ananta, Runtuboi, & Sala, 2017; Brown et al., 2018; Sadovy de Mitcheson, Suharti, & Colin, 2019; Text S3). Global studies have indicated that healthy coral reefs without fishing typically sustain 1,000 kg/ha of fish biomass (Karr et al., 2015; MacNeil et al., 2015; McClanahan et al., 2019), so it is encouraging that North Raja Ampat sustainable fishing areas maintain fish biomass above this level. While reef fish biomass is variable between MPAs, it is generally highest in MPAs associated with tourism (e.g., Dampier Strait MPA; Table S4). Livelihood assessments in MPAs with high tourism have indicated a shift away from fisheries to wage labor as a primary occupation (Claborn et al., 2017), even though fishing rates have not declined (Ahmadia et al., 2017). It has also been suggested that frequent dive tourism may serve to act as a deterrent to illegal fishing as some tourism operators actively support MPA management by contributing additional surveillance (Nikijuluw, Papilaya, & Boli, 2017). Further investigation is needed to understand drivers of change in fish biomass within the BHS.

Stable coral reef ecosystem health within MPAs can, at least in part, be attributed to MPA management that has mitigated many local threats such as destructive and overfishing. While remote Indonesian reefs generally have higher fish biomass (Campbell et al., 2020), remoteness is unlikely responsible for BHS MPA outcomes. Fishers from other Indonesian provinces and neighboring countries travel large distances to access the rich fishing grounds within the BHS (e.g., Jaiteh et al., 2016), and some more remote sites within the BHS have lower fish abundance than those closer to major cities (Andradi-Brown et al., 2021). Our results suggest that, overall, MPAs are leading to positive coral reef outcomes, and can help inform adaptive management for ongoing regional fisheries challenges for the BHS.

Together, West Papua and Papua provinces contain approximately 10% of the world's mangroves (Hamilton & Casey, 2016), making regional mangrove conservation of global importance. Low population densities and relative isolation have likely contributed to low loss of mangroves in much of the region. Within BHS MPAs, mangrove cover appears to be relatively stable. Kaimana is a notable exception, where 315 ha was lost between 1996 and 2016. Threats to mangroves are increasing in the BHS, leading to several new initiatives to increase mangrove protection (Text S4). Threats include clearance for agriculture, aquaculture and logging, mining activities, and increasing coastal populations (Howard et al., 2017; Indrawan et al., 2019). Mangroves are subject to legal protection under a Presidential decree (No. 32, 1990), several regency regulations, and the Manokwari Declaration committing West Papua and Papua provinces to maintaining forest cover including mangroves (Cámara-Leret et al., 2019; Text S4). Three new BHS MPAs have been created specifically to protect mangroves (Sorong, South Sorong, and Bintuni Bay) and Kaimana MPA boundaries deliberately included large mangrove stands. Some BHS MPAs are also trialing finance based on mangrove blue carbon (carbon stored in mangrove forests and their associated sediments; e.g., Howard et al., 2017). Many communities also maintain local tenure systems contributing to the retention of mangrove forests—although these are increasingly challenged (Fatem, 2019). It is clear that further efforts across all governance scales will be required to secure BHS mangroves into the future.

Seagrass is the least studied critical habitat in the BHS, with few studies since previous reviews (Mangubhai et al., 2012; McKenzie et al., 2006). Seagrass beds are known to provide important habitat for dugongs and sea turtles in the region (Putrawidjaja, 2000; Salm et al., 1982), as well as support important fisheries species and provide carbon sequestration services (McKenzie et al., 2006; Unsworth et al., 2018). A recent stakeholder workshop identified high risks to seagrass beds in West Papua from coastal reclamation and development, as well as sedimentation and poor water quality from deforestation (Unsworth et al., 2018). There is some limited evidence of seagrass declines outside of MPAs within Cenderawasih Bay caused by pollution (Unsworth et al., 2018), but no trends in extent or health are available for the region. Seagrass ecosystems require urgent mapping and further study within the BHS to determine appropriate conservation actions.

4.5 | Challenges and opportunities in a changing world

Alongside increasing population and rising economic well-being in Indonesia (World Bank, 2019a, 2019b) comes development and environmental and social change. Conservation in areas where there is a strong interface between people and the environment—such as the BHS—needs to respect community rights to development to increase prosperity. Conservation can help facilitate sustainable development and sustainable use of natural resources for long-term health of both people and the environment. For MPAs in the BHS, this means working more closely across sectors, continuing to develop management capacity, and anticipating and adapting management and financing mechanisms to address the needs of local communities while ensuring long-term health and productivity of coastal ecosystems.

Despite some shortcomings, the BHS MPA network is successfully preventing biodiversity and ecosystem service loss. Overall, coastal ecosystems appear fairly intact, with stable or increasing conditions in many of the older BHS MPAs. However, the trajectory of both MPA network expansion and broad management effectiveness and capacity increases need to continue to keep pace with existing and emerging threats. This study highlights key priorities to focus on: (a) build management capacity to increase management effectiveness from patrolling to adaptive management; (b) build further community awareness and engagement in coastal ecosystem conservation and governance especially around fisheries to ensure equitable distribution of MPA benefits; (c) manage the influx of tourism; (d) develop appropriate mitigation strategies for areas where increasing access and infrastructure are increasing coastal fisheries pressure and coastal pollution; and (e) secure sustainable financing for MPA management in the future (e.g., fully capitalized Blue Abadi Fund, ongoing and increased commitments of government budget, and tourism fees).

ACKNOWLEDGMENTS

The authors wish to thank Laura Veverka for assistance. We thank the Conservation International ecological monitoring team, including: Abdi Wunanto Hasan, Katherina Tjandra, Andi Yasser Fauzan, Sadik Mayor, Richard Tanamal, and Dedik Priyo Utomo; the crew of "Imbekwan" including: Capt. Wempy Boari, Gustaf Manope, Vikly Tumipa, Piter Sumbiaganan, Yunus Rumbewas; and the UPTD-BLUD R4 monitoring team: Rudi Dimara, Elvis Mambrasar, Imanuel Mofu, Aser Burdam, Naftali Manggara, Ali Oherenan. We gratefully acknowledge the Walton Family Foundation and Margaret A. Cargill Philanthropies for financial support for this project. We thank the editor and two anonymous reviewers for comments that improved this manuscript.

CONFLICT OF INTEREST
The authors declare no conflicts of interest.

DATA AVAILABILITY STATEMENT
Data associated with this manuscript is available in the Supporting Information.

ETHICS STATEMENT
No ethics review was required for data presented in this manuscript.

ORCID
Dominic A. Andradi-Brown https://orcid.org/0000-0001-5191-5225

REFERENCES
Adams, V. M., Iacona, G. D., & Possingham, H. P. (2019). Weighing the benefits of expanding protected areas versus managing existing ones. *Nature Sustainability*, *2*(5), 404–411. https://doi.org/10.1038/s41893-019-0275-5

Ahmadia, G. N., Awaludinnoer, Glew, L., Pakiding, F., Harris, J., Hidayat, N., … Purwanto, (2017). *2016 state of the Bird's Head Seascape MPA network report*. Washington, DC, Jakarta, Indonesia, and Manokwari, Indonesia: World Wildlife Fund, Conservation International, The Nature Conservancy, and Universitas Papua. https://doi.org/10.6084/m9.figshare.6977738.v1

Ahmadia, G. N., Wilson, J. R., & Green, A. L. (2013). Coral reef monitoring protocol for assessing marine protected areas in the Coral Triangle. *Coral Triangle Support Partnership*. https://doi.org/10.6084/m9.figshare.5309656.v1

Ainsworth, C. H., Pitcher, T. J., & Rotinsulu, C. (2008). Evidence of fishery depletions and shifting cognitive baselines in Eastern Indonesia. *Biological Conservation*, *141*(3), 848–859. https://doi.org/10.1016/j.biocon.2008.01.006

Allen, G. R., & Erdmann, M. V. (2009). Reef fishes of the Bird's Head peninsula, West Papua, Indonesia. *Check List*, *5*(3), 587–628. https://doi.org/10.15560/5.3.587

Allen, G. R., & Erdmann, M. V. (2012). *Reef fishes of the east indies: Volumes I–III*. Perth, Australia: Tropical Reef Research.

Alongi, D. M. (2007). 5.4 mangrove forests of Papua. In A. J. Marshall & B. M. Beehler (Eds.), *The ecology of Papua (part two)*. Singapore: Periplus Editions.

Andradi-Brown, D. A., Beer, A. J. E., Colin, L., Hastuti Head, C. E. I., Hidayat, N. I., Lindfield, S. J., … Ahmadia, G. N. (2021). Highly diverse mesophotic reef fish communities in Raja Ampat, West Papua. *Coral Reefs*, *40*, 111–130. https://doi.org/10.1007/s00338-020-02020-7

Anna, Z., & Saputra, D. S. (2017). Economic valuation of whale shark tourism in Cenderawasih Bay National Park, Papua, Indonesia. *Biodiversitas, Journal of Biological Diversity*, *18*(3), 1026–1034. https://doi.org/10.13057/biodiv/d180321

Atmodjo, E., Lamers, M., & Mol, A. (2017). Financing marine conservation tourism: Governing entrance fees in Raja Ampat, Indonesia. *Marine Policy*, *78*, 181–188. https://doi.org/10.1016/j.marpol.2017.01.023

Atmodjo, E., Lamers, M., & Mol, A. (2019). Governing dynamics in marine conservation tourism in Raja Ampat, Indonesia. *Tourism Planning and Development*, *17*(6), 655–673. https://doi.org/10.1080/21568316.2019.1686652

Awaludinnoer, Pada, D., Purwanto, Veverka, L., & Andradi-Brown, D. A. (2021). Case study 13: Raja Ampat marine protected area network, West Papua, Indonesia. C. Phua D. A. Andradi-Brown S. Mangubhai G. N. Ahmadia S. L. Mahajan K Larsen … S. Wells. *Marine protected and conserved areas in the time of COVID*. PARKS, 27(SI)(85–102). https://doi.org/10.2305/IUCN.CH.2021.PARKS-27-SICP.en.

Badan Pusat Statistik. (2010). *Indonesian population census, 2010*. Jakarta, Indonesia. https://www.bps.go.id.

Bates, D., Mächler, M., Bolker, B., & Walker, S. (2015). Fitting linear mixed-effects models using lme4. *Journal of Statistical Software*, *67*(1), 1–48. https://doi.org/10.18637/jss.v067.i01

Bowen, B. W., Rocha, L. A., Toonen, R. J., & Karl, S. A. (2013). The origins of tropical marine biodiversity. *Trends in Ecology and Evolution*, *28*(6), 359–366. https://doi.org/10.1016/j.tree.2013.01.018

Brown, C. J., Parker, B., Ahmadia, G. N., Ardiwijaya, R., Purwanto, & Game, E. T. (2018). The cost of enforcing a marine protected area to achieve ecological targets for the recovery of fish biomass. *Biological Conservation*, *227*, 259–265. https://doi.org/10.1016/j.biocon.2018.09.021.

Bunting, P., Rosenqvist, A., Lucas, R. M., Rebelo, L., Hilarides, L., Thomas, N., … Finlayson, C. M. (2018). The global mangrove watch—A new 2010 global baseline of mangrove extent. *Remote Sensing*, *10*(10), 1669. https://doi.org/10.3390/rs10101669

Cámara-Leret, R., Schuiteman, A., Utteridge, T., Bramley, G., Deverell, R., Fisher, L. A., … Heatubun, C. (2019). The Manokwari declaration: Challenges ahead in conserving 70% of Tanah Papua's forests. *Forest and Society*, *3*(1), 148–151. https://doi.org/10.24259/FS.V3I1.6067

Campbell, S. J., Darling, E. S., Pardede, S., Ahmadia, G., Mangubhai, S., Amkieltiela, Estradivari, & Maire, E. (2020). Fishing restrictions and remoteness deliver conservation outcomes for Indonesia's coral reef fisheries. *Conservation Letters*, *13*(2), e12698. https://doi.org/10.1111/conl.12698.

Claborn, K., Glew, L., Matualage, D., Mohebalian, P., Pakiding, F., Ahmadia, G. N., & Mascia, M. B. (2017). *Status and trends in human well-being in Selat Dampier MPA*. Washington, D.C., United States, Manokwari, Indonesia, and Arlington, V.A., United States: World Wildlife Fund, University of Papua, and Conservation International. https://doi.org/10.6084/m9.figshare.14135792.

Cook, C. N., Carter, R. W., & Hockings, M. (2014). Measuring the accuracy of management effectiveness evaluations of protected areas. *Journal of Environmental Management*, *139*, 164–171. https://doi.org/10.1016/j.jenvman.2014.02.023.

DeVantier, L., Turak, E., & Allen, G. (2009). Reef-scapes, reef habitats and coral communities of Raja Ampat, Bird's Head Seascape, Papua, Indonesia. In *Report to The Nature Conservancy*. Bali, Indonesia. The Nature Conservancy.

Dirhamsyah. (2016). Setbacks in the development of marine protected areas in Indonesia. *Australian Journal of Maritime & Ocean Affairs*, *8*(2), 87–100. https://doi.org/10.1080/18366503.2016.1187781.

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*. Bali: The Nature Conservancy.

Eakin, C. M., Sweatman, H. P. A., & Brainard, R. E. (2019). The 2014–2017 global-scale coral bleaching event: Insights and impacts. *Coral Reefs*, *38*(4), 539–545. https://doi.org/10.1007/s00338-019-01844-2.

ESRI. (2020). *ArcGIS*. Redlands, CA: Environmental Systems Research Institute Retrieved from https://www.arcgis.com/index.html

Fatem, S. M. (2019). Connecting social forestry to conservation policies in Tanah Papua. *Forest and Society*, *3*(1), 141–147. https://doi.org/10.24259/FS.V3I1.5865

Fatem, S. M., Syuf, Y., Baru, J., Marwa, J., Runtuboi, Y. Y., Tawer, V., … Runtuboi, F. R. (2020). The Sausapor declaration: Challenges in promoting good governance to protect customary communities and natural resources in Tambrauw district, West Papua. *Forest and Society*, *4*(2), 330–337. https://doi.org/10.24259/FS.V4I2.9346

Friess, D. A., Rogers, K., Lovelock, C. E., Krauss, K. W., Hamilton, S. E., Lee, S. Y., … Shi, S. (2019). The state of the world's mangrove forests: Past, present, and future. *Annual Review of Environment and Resources*, *44*(1), 89–115. https://doi.org/10.1146/annurev-environ-101718-033302.

Froese, R., & Pauly, D. (2019). *FishBase*. Retrieved from https://www.fishbase.org.

Gill, D. A., Mascia, M. B., Ahmadia, G. N., Glew, L., Lester, S. E., Barnes, M., … Fox, H. E. (2017). Capacity shortfalls hinder the performance of marine protected areas globally. *Nature*, *543*, 665–669. https://doi.org/10.1038/nature21708.

Green, A. L., & Mous, P. J. (2008). Delineating the coral triangle, its ecoregions and functional seascapes. Version 5.0. *The Nature Conservancy Coral Triangle Program Report*.

Groff, D., Ihsan, E. N., Amkieltiela, Harris, J., Ahmadia, G. N., & Estradivari. (2016). *Ecological status of Teluk Cenderawasih National Park – 2016 Technical Report*. Washington, DC, and Jakarta, Indonesia: World Wildlife Fund. https://doi.org/10.6084/M9.FIGSHARE.12111492

Hamilton, S. E., & Casey, D. (2016). Creation of a high spatio-temporal resolution global database of continuous mangrove forest cover for the 21st century (CGMFC-21). *Global Ecology and Biogeography*, *25*(6), 729–738. https://doi.org/10.1111/geb.12449.

Heazle, M., & Butcher, J. G. (2007). Fisheries depletion and the state in Indonesia: Towards a regional regulatory regime. *Marine Policy*, *31*, 276–286. https://doi.org/10.1016/j.marpol.2006.08.006.

Howard, J., McLeod, E., Thomas, S., Eastwood, E., Fox, M., Wenzel, L., & Pidgeon, E. (2017). The potential to integrate blue carbon into MPA design and management. *Aquatic Conservation: Marine and Freshwater Ecosystems*, *27*(S1), 100–115. https://doi.org/10.1002/aqc.2809.

Huffard, C. L., Erdmann, M. V., & Gunawan, T. R. (2012). Geographic priorities for marine biodiversity conservation in Indonesia. In *Coral Triangle Initiative on coral reefs, fisheries, and food security*. Jakarta, Indonesia: Ministry of Marine Affairs and Fisheries.

Huffard, C. L., Wilson, J., Hitipeuw, C., Rotinsulu, C., Mangubhai, S., Erdmann, M. V., … Toha, H. (2012). *Ecosystem based management in the Bird's Head seascape Indonesia: Turning science into action. Indonesia: Ecosystem based management program: Conservation International*. Jakarta & Bali, Indonesia: The Nature Conservancy, and World Wildlife Fund.

Indrawan, M., Sumule, A., Wijaya, A., Kapisa, N., Wanggai, F., Ahmad, M., … Heatubun, C. D. (2019). A time for locally driven development in Papua and West Papua. *Development in Practice*, *29*(6), 817–823. https://doi.org/10.1080/09614524.2019.1609907.

Jaiteh, V. F., Lindfield, S. J., Mangubhai, S., Warren, C., Fitzpatrick, B., & Loneragan, N. L. (2016). Higher abundance of marine predators and changes in fishers' behavior following spatial protection within the world's biggest shark fishery. *Frontiers in Marine Science*, *3*, 43. https://doi.org/10.3389/fmars.2016.00043.

Karr, K. A., Fujita, R., Halpern, B. S., Kappel, C. V., Crowder, L., Selkoe, K. A., … Rader, D. (2015). Thresholds in Caribbean coral reefs: Implications for ecosystem-based fishery management. *Journal of Applied Ecology*, *52*(2), 402–412. https://doi.org/10.1111/1365-2664.12388.

KKJI. (2012). *Pedoman Teknis Evaluasi Efektivitas Pengelolaan Kawasan Konservasi Perairan, Pesisir Dan Pulau-Pulau Kecil (E-KKP3K)*. Pesisir dan Pulau-Pulau Kecil, Kementerian Kelautan dan Perikanan: Direktorat Kawasan Konservasi dan Jenis Ikan, Direktorat Jenderal Kelautan.

Kuempel, C. D., Adams, V. M., Possingham, H. P., & Bode, M. (2018). Bigger or better: The relative benefits of protected area network expansion and enforcement for the conservation of an exploited species. *Conservation Letters*, *11*(3), e12433. https://doi.org/10.1111/conl.12433.

Kuznetsova, A., Brockhoff, P. B., & Christensen, R. H. B. (2017). LmerTest package: Tests in linear mixed effects models. *Journal of Statistical Software*, *82*(1), 1–26. https://doi.org/10.18637/jss.v082.i13

Larsen, S. N., Leisher, C., Mangubhai, S., Muljadi, A., & Tapilatu, R. (2011). *Report on a coastal rural appraisal in Raja Ampat regency*. Bali, West Papua, Indonesia: The Nature Conservancy.

Luke, S. G. (2017). Evaluating significance in linear mixed-effects models in R. *Behavior Research Methods*, *49*(4), 1494–1502. https://doi.org/10.3758/s13428-016-0809-y.

MacNeil, M. A., Graham, N. A. J., Cinner, J. E., Wilson, S. K., Williams, I. D., Maina, J., … McClanahan, T. R. (2015). Recovery potential of the world's coral reef fishes. *Nature*, *520*, 341–344. https://doi.org/10.1038/nature14358.

Mangubhai, S., Erdmann, M. V., Wilson, J. R., Huffard, C. L., Ballamu, F., Hidayat, N. I., … Wen, W. (2012). Papuan Bird's Head Seascape: Emerging threats and challenges in the global center of marine biodiversity. *Marine Pollution Bulletin*, *64*(11), 2279–2295. https://doi.org/10.1016/j.marpolbul.2012.07.024.

McClanahan, T. R., Schroeder, R. E., Friedlander, A. M., Vigliola, L., Wantiez, L., Caselle, J. E., … Cinner, J. E. (2019).

Global baselines and benchmarks for fish biomass: Comparing remote reefs and fisheries closures. *Marine Ecology Progress Series*, *612*, 167–192. https://doi.org/10.3354/meps12874

McKenzie, C. R., Coles, R., & Erftemeijer, P. (2006). 5.3 Seagrass ecosystems of Papua. In A. J. Marshall & B. M. Beehler (Eds.), *The ecology of Papua (part two)*. Singapore: Periplus Editions.

McLeod, E., Szuster, B., & Salm, R. (2009). Sasi and marine conservation in Raja Ampat, Indonesia. *Coastal Management*, *37*(6), 656–676. https://doi.org/10.1080/08920750903244143.

Mudjirahayu, Bawole, R., Rembet, U. N. W. J., Ananta, A. S., Runtuboi, F., & Sala, R. (2017). Growth, mortality and exploitation rate of *Plectropomus maculatus* and *P. oligocanthus* (Groupers, Serranidae) on Cenderawasih Bay National Park, Indonesia. *The Egyptian Journal of Aquatic Research*, *43*(3), 213–218. https://doi.org/10.1016/j.ejar.2017.09.002.

Nikijuluw, V. P. H., Papilaya, R. L., & Boli, P. (2017). *Daya Dukung Pariwisata Berkelanjutan Raja Ampat*. Raja Ampat, Indonesia: Conservation International.

Palomares, M. L. D., Heymans, J. J., & Pauly, D. (2007). Historical ecology of the Raja Ampat Archipelago, Papua Province, Indonesia. *History and Philosophy of Life Sciences*, *29*(1), 35–56.

Papilaya, R. L., Boli, P., & Nikijuluw, V. P. H. (2019). Carrying capacity of diving tourism in Dampier Strait Marine Conservation Area – District of Raja Ampat. *IOP Conference Series: Earth and Environmental Science*, *246*, 012060. https://doi.org/10.1088/1755-1315/246/1/012060

Phua, C., Andradi-Brown, D. A., Mangubhai, S., Ahmadia, G. N., Mahajan, S. L., Larsen, K., … Wells, S. (2021). Marine protected and conserved areas in the time of COVID. *PARKS*, *27*(SI), 85–102. https://doi.org/10.2305/IUCN.CH.2021.PARKS-27-SICP.en.

Pohlert, T. (2020). *Trend: Non-parametric trend tests and change-point detection (version 1.1.2). R. R Package*. Retrieved from https://CRAN.R-project.org/package=trend.

Putrawidjaja, M. (2000). *Marine species trade in Irian Jaya. Cendrawasih Bay National Park Case (report)*. Jayapura: Conservation Science, WWF-Indonesia-Sahul Bioregion.

R Core Team. (2020). *R: A language and environment for statistical computing*. Vienna, Austria: R Foundation for Statistical Computing Retrieved from https://www.R-project.org/

Renema, W., Bellwood, D. R., Braga, J. C., Bromfield, K., Hall, R., Johnson, K. G., … Pandolfi, J. M. (2008). Hopping hotspots: Global shifts in marine biodiversity. *Science*, *321*, 654–657. https://doi.org/10.1126/science.1155674.

Sadovy de Mitcheson, Y., Suharti, S. R., & Colin, P. L. (2019). Quantifying the rare: Baselines for the endangered Napoleon Wrasse, *Cheilinus undulatus*, and implications for conservation. *Aquatic Conservation: Marine and Freshwater Ecosystems*, *29*(8), 1285–1301. https://doi.org/10.1002/aqc.3124.

Salm, R. V., Petocz, R. G., & Soehartono, T. (1982). *Survey of coastal areas in Irian Jaya*. Bogor, Indonesia: UNDP/FAO National Parks Development Project; WWF Indonesia Program.

Staub, F., & Hatziolos, M. E. (2004). *Score card to assess progress in achieving management effectiveness goals for marine protected areas*. Washington, DC: World Bank.

Stolton, S., Hockings, M., Dudley, M., Mackinnon, K., & Whitten, T. (2003). *Reporting progress in protected areas: A site-level management effectiveness tracking tool*. Gland, Switzerland: World Bank and WWF Alliance for Forest Conservation.

Stolton, S., Hockings, M., Dudley, N., MacKinnon, K., Whitten, T., & Leverington, F. (2007). *Reporting progress in protected areas: A site level management effectiveness tracking tool* (2nd ed.). Gland, Switzerland: World Bank and WWF Forest Alliance.

Tapilatu, R. F., Woma, H, & Batubara, P. P. (2017). Status of sea turtle populations and its conservation at Bird's Head Seascape, Western Papua, Indonesia. *Biodiversitas, Journal of Biological Diversity*, *18* (1), 129–136. https://doi.org/10.13057/biodiv/d180118.

Unsworth, R. K. F., Ambo-Rappe, R., Jones, B. L., La Nafie, Y. A., Irawan, A., Hernawan, U. E., … Cullen-Unsworth, L. C. (2018). Indonesia's globally significant seagrass meadows are under widespread threat. *Science of the Total Environment*, *634*, 279–286. https://doi.org/10.1016/j.scitotenv.2018.03.315.

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, Journal of Coral Reef Studies*, *11*(2), 91–100. https://doi.org/10.3755/galaxea.11.91.

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*(31–32), 1905–1924. https://doi.org/10.1080/00222933.2011.573098.

Wiadnya, D. G. R., Mous, P. J., Djohani, R., Erdmann, M. V., Halim, A., Knight, M., … Pet, J. S. (2006). Marine capture fisheries policy formulation and the role of marine protected areas as a tool for fisheries management in Indonesia. *Marine Research in Indonesia*, *30*, 33–45. https://doi.org/10.14203/mri.v30i0.422.

Wijayanto, D. (2016). Fisheries development strategies of Biak Numfor Regency, Indonesia. *Aquatic Procedia*, *7*(2016), 28–38. https://doi.org/10.1016/j.aqpro.2016.07.004

Wilson, J. R., & Green, A. L. (2009). *Biological monitoring methods for assessing coral reef health and management effectiveness of marine protected areas in Indonesia. 1/09. Indonesia marine program report*. Bali, Indonesia: The Nature Conservancy.

World Bank. (2019a). *GDP growth (annual %) – Indonesia*. Washington, DC: World Bank.

World Bank. (2019b). *Population, total – Indonesia*. Washington, DC: The World Bank.

SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of this article.

How to cite this article: Purwanto, Andradi-Brown DA, Matualage D, et al. The Bird's Head Seascape Marine Protected Area network—Preventing biodiversity and ecosystem service loss amidst rapid change in Papua, Indonesia. *Conservation Science and Practice*. 2021;e393. https://doi.org/10.1111/csp2.393