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Movement and retention of derelict fishing nets in Northwestern Hawaiian Island reefs

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ABSTRACT

Derelict fishing nets pose hazards to marine systems as they travel through the ocean or become ensnared on coral reefs. Understanding of the movement of nets within shallow atolls can help to optimize operations to protect these shallow reefs. In 2018, six derelict fishing nets at Manawai (Pearl and Hermes Reef) in the Northwestern Hawaiian Islands were tagged with satellite-transmitting buoys and tracked for three years. This study reveals that nets that enter the atoll from the northeast travel southwest towards the center of the atoll, and nets in the center can remain ensnared on the same reef for at least three years. This study shows that satellite buoys are a successful approach to tracking derelict net movement, and can inform future debris removal missions.

1. Introduction

Fishing gear that has been lost, abandoned, or discarded in the open ocean poses a threat to marine communities. Large derelict fishing nets may entangle wildlife (Boland and Donohue, 2003; Henderson, 2001; Votier et al., 2011), destroy reefs (Macfadyen et al., 2009; Suka et al., 2020), and pose navigational hazards to vessels (Hong et al., 2017). Nets are increasingly made out of plastic which takes much longer to degrade (Macfadyen et al., 2009), increasing the lifespan of these derelict nets and the extent of potential damage they can inflict on both marine life and marine environments. In recent years as derelict nets have become more abundant and more durable, research has expanded to investigate not only the impacts of derelict nets on the ecosystem, but how to best locate, track, and remove nets to prevent them from inflicting further harm (McElwee et al., 2012).

One unique marine environment that is impacted by derelict fishing nets is the Northwestern Hawaiian Islands (NWHI) — a remote archipelago of islands, atolls, and reef systems that extend 2200 km to the northwest of the main Hawaiian Islands and is part of the protected Papahānaumokuākea Marine National Monument established in 2006 (www.papahanaumokuakea.gov). This uninhabited island chain in the North Pacific Ocean differs from the main Hawaiian Islands in that it is dominated by shallow-water lagoons and coral reef ecosystems, rather than emergent land. These shallow-reef systems act as a sieve for derelict fishing nets as they are transported by currents through the North Pacific Subtropical Convergence Zone. In particular, debris accumulation in the NHWI increases when the North Pacific Subtropical Convergence Zone dips southward and nears the island chain (Donohue et al., 2001; Donohue and Foley, 2007; Howell et al., 2012; Kubota, 1994; Morishige et al., 2007; Pichel et al., 2007) which occurs annually in the winter and early spring (Howell et al., 2012).

Previous studies in the NWHI have quantified the type, amount, and accumulation rate of derelict fishing nets (Boland and Donohue, 2003; Dameron et al., 2007; Donohue et al., 2001), and most recently, the damaging effects of such nets that snag on and smother corals directly beneath them (Suka et al., 2020). However, many questions still remain about the overall scale of impact on shallow-reef systems caused by derelict nets, which require an understanding of the spatial movement patterns and extent of retention of nets in the archipelago. While there have been models and simulations of movement of floating debris in the open waters of the North Pacific based on ocean currents and wind patterns (Kubota, 1994; Wakata and Sugimori, 1990), and although a study in 2020 surveyed locations of derelict nets caught by longline fishing vessels (Uhrin et al., 2020), little has been done to ground-truth the application of these models when predicting net movement in and around shallow-reef systems of the NWHI.

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Fig. 1. Divers attach a satellite buoy to a derelict fishing net conglomerate comprised of buoys, lines, and nets in Manawai during the 2018 mission. Photo credit: NOAA/Steven Gnam.

Here, we offer a proof-of-concept for successfully tracking nets in shallow, coral reef environments to better understand their movement through time in these critical habitats. We followed the movement of six nets tagged with GPS-enabled satellite buoys over the course of three years as a pilot effort for method development. The data collected provide information on the spatial extent of net movement and the duration of time derelict nets remain stationary, ensnared on coral reefs. These data can feed into larger collaborative efforts that combine on-site observations with remote sensing and modeling techniques to improve our ability to locate, track, and remove marine debris (Maximenko et al., 2019; McElwee et al., 2012). With increased regional knowledge of net movement, more money and time can be saved by concentrating clean-up efforts in areas where nets are known to most often travel and remain stationary, thus having the most impact on reefs.

2. Methods

In late September 2018, we attached satellite buoys to conglomerates of derelict fishing nets found inside the reef crest at Manawai (also known as Holoikauaua or Pearl and Hermes Reef). Manawai is an atoll towards the northwestern end of Papahānaumokuākea that has an outer fringing reef, contains several low-lying islands, and is about 30 km across at the widest point. Prevailing trade winds intersect the atoll on the northeast side, contributing to a broad, shallow area of sandy habitat just inside the reef crest that opens up into a lagoon that consists of 800 km^2 of maze-like reticulated coral reef structures. Search efforts for suitable nets to tag were concentrated on the northeast side of the atoll, where nets are most likely to enter due to those prevailing winds. Nets were selected for tagging if >75% of the volume was floating at the surface, as opposed to hanging below the surface (Fig. 1), had minimum average measurements of 1 m in length, width, and height, and had a low fouling level (<50%) indicating that they were recent arrivals to the atoll. These metrics were visually estimated by trained divers, and all six selected nets were found ensnared on reefs; even though the nets were mostly buoyant, the lower portion of each was snagged on the reef. Satlink solar-powered satellite buoys (model ISL+: https://www.satlink.es/en/smart-buoys/satlink-isl-buoy/) weighing 13.7 kg with a 40.6 cm diameter and 36.8 cm height were affixed to the nets with industrial strength nylon zip ties (Fig. 1); otherwise the nets were not moved or disturbed.

The buoys usually transmitted geographic coordinates once every 4 h (range of time between transmissions varied from 1 min to 50 days) until transmission ceased potentially due to technical failures, insufficient charging of the solar-powered unit, or until the buoys broke free. For each transmission period, we considered a net to be stationary if the distance traveled from the previous transmission was less than the maximum length of the net in order to account for movement in the water while the net was still attached to the reef. We then calculated the total time and distances that each net was stationary versus moving and reported the net movement rates when traveling (km/day).

In an attempt to ground truth the net locations while they were deployed, we partnered with NOAA's National Environmental Satellite Data and Information Service (NESDIS) to obtain high-resolution satellite imagery at the last known coordinates of each net, but the images were not able to detect any visual anomalies that would indicate marine debris on the surface of the ocean. A debris removal mission returned to Manawai in September of 2021, and a team visited the last known stationary locations of the nets. Of the six tagged nets, four nets were relocated. All four had broken zip ties, indicating that the buoys had broken free. The removal team reported the coordinates of each net, which we used to analyze net movement from the deployment time through these final stationary positions within the atoll.

Although we were unable to relocate the other two nets in person, we assume that the buoys were still attached due to their slow movement rate. In contrast, we determined that the other four buoys broke free from their nets based on movement rates 20+ times greater (11 to 21 km/day) than buoys with confirmed nets still attached. Hence, we truncated the net movement time series to exclude these 'buoy-only' trajectories for the subsequent analysis.

Locations were overlaid on a satellite image of Manawai. Locations were downloaded using ELB 3010 Manager v. 2014.6332.42068, data were formatted in R v. 3.6.1 (R Core Team, 2020), and locations were mapped using ArcMap v.10.6.1. Data used in this study are available through NOAA's National Centers for Environmental Information (https://www.ncei.noaa.gov/access/metadata/landing-page/bin/iso?id=gov.noaa.nodc:0229980).

3. Results

Nets that were tagged near the northeast perimeter of the atoll traveled southwest towards the reticulated reef structure in the center of the atoll, while nets that were tagged in the interior of the atoll tended to

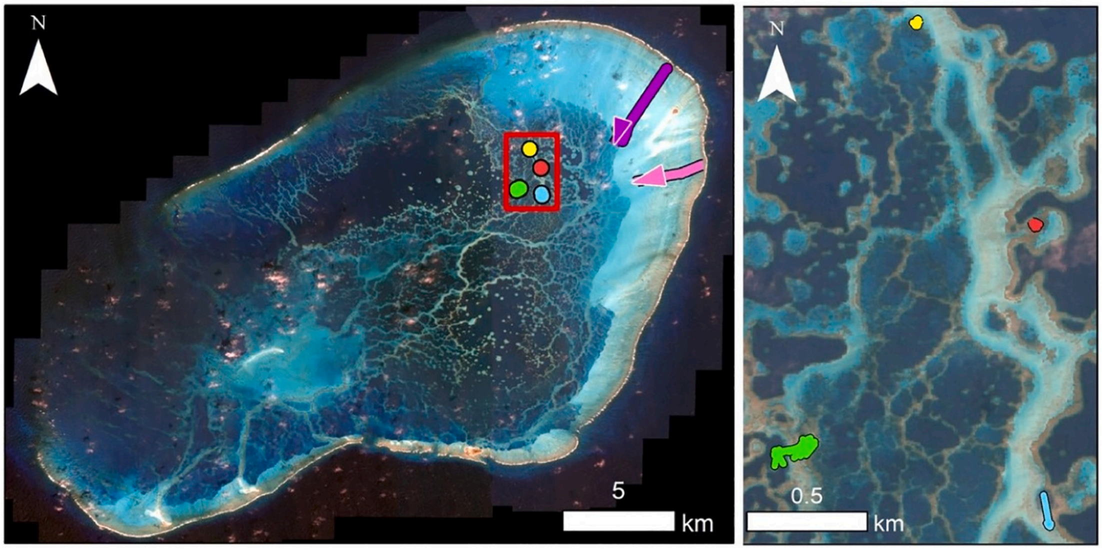

Fig. 2. Tracks of the six nets that were tagged in Manawai. The left panel shows the extent of the atoll and tracks of all six nets; each color represents a different buoy (see Table 1), and the red rectangle indicates the extent of the map on the right panel. The right panel shows more detail for the four interior nets and their slight movements; the yellow and red track lines are not visible at this scale as these nets moved minimal distances from their tagging location. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Table 1
Derelict net information. Net ID indicates the color of the net in the figures. Tagged location indicates if the net was tagged in the interior of the atoll or near the perimeter. Net measurements were estimated by divers prior to attaching satellite buoys. Start date is when the net was tagged. Summaries of time and movement of each net were calculated from the buoy transmissions of net locations. The final distance from the initial location was calculated using the last known transmissions for the pink and purple net, and the locations marked by the survey team for the other four nets in September 2021.

Net ID	Tagged location	Size (average length/width/depth in meters)	Start date	Days tracked	Total distance traveled (km)	Final distance from initial location (km)	Days stationary (absolute/% of days)	Days traveling (absolute/% of days)	Movement rate when traveling (km/day)
Blue	Interior	3/2/1	9/30/2018	425	1.7	<0.1	368.3/86.7%	57/5.3%	0
Red	Interior	8/3/1.5	10/1/2018	486	0.5	<0.1	479.1/98.6%	6.8/0.6%	0.1
Green	Interior	5/2.5/2	10/1/2018	803	5.2	<0.1	733/91.3%	70.5/6.5%	0.1
Yellow	Interior	8/1/1.2	10/1/2018	132	0.1	<0.1	127.9/96.9%	4.5/0.4%	0
Purple	Perimeter	2/2/3	9/30/2018	64	5.4	4.0	37.2/58.1%	27.2/42.6%	0.2
Pink	Perimeter	7.5/2/2	10/1/2018	55	2.8	2.7	49/89.1%	6.2/11.2%	0.5

stay ensnared on a small area of reef for almost three years. The two perimeter nets that traveled the farthest from their initial tagged location traveled from the barrier reef southwest towards the center (Fig. 2, purple and pink tracks) along similar trajectories, although with different timing; the pink net began to travel after three days and traveled 2.7 km, while the purple net began to travel after 58 days and traveled 4 km. The movement rates of these nets averaged 0.35 km/day. Although these two perimeter nets did travel the farthest, they still remained stationary for the majority of their time – the purple net remaining in the initial tagging location for the majority of its stationary time (58%) and the pink net remaining stationary about halfway down the track line, and again where the track line ended, for a total of 89% of the net's time (Table 1).

The four interior nets stayed in relatively the same location for nearly three years. Although the green net collectively traveled 5 km over that period of time, it stayed within 0.15 km of the initial tagging location as it drifted back and forth across the reef. Of the four nets that were relocated, stationary time ranged from 87 to 99% of the time deployed, and their extremely slow movement rate averaged 0.05 km/day. The red and yellow nets remained stationary on the same area of reef, while the green and blue nets remained within 100 m of the original tagging location (Table 1).

4. Discussion

Satellite buoys can be a useful tool for tracking movement in marine environments. Here, we have demonstrated that such tags are effective at tracking movement and retention of derelict fishing nets, provided the satellite tag is effectively secured to the net. Based on the limited number of nets tagged in this study, our results suggest nets which enter the atoll from the northeast tend to move southwest at a slow pace (0.35 km/day) towards the reticulated reef structure in the central interior of the atoll, at which point they can remain in place on a single reef for extended periods of time (1079 days). This net movement aligns with the prevailing wind direction at that time (October–December, Wyrtki and Meyers, 1976) suggesting wind driven movement until the nets are snagged by the numerous reticulated reefs located in the atoll interior. Indeed, the four nets tagged in the atoll interior remained stationary for >86% of the time they were tracked over three years, and moved only 12–53 m from the original tagging location. These are likely also conservative estimates as we do not know how long these nets were on the reef before they were found by our teams. One previous study estimated that nets remained in place in the Puget Sound for up to 24 years, although the median time was one year (Good et al., 2010). This study builds on that evidence to show that nets can remain in place for close to three years, and remain within the same local reef network for that duration.

While this study has furthered our understanding of net movement, it also highlights the need to continue on-site observations of derelict fishing nets to further understand the consequences of their retention and movement on marine systems. We assume that the stationary nets we tracked were ensnared on the underlying coral reef substrate where they can negatively impact the corals (Suka et al., 2020) and pose entanglement hazards to wildlife such as seabirds, sea turtles, monk seals, and fish who frequent these reefs (Boland and Donohue, 2003; Donohue et al., 2001; Fowler, 1987; Gall and Thompson, 2015; Gilardi et al., 2010; Good et al., 2010; Harting et al., 2014; Moore et al., 2009; Triessnig et al., 2012). Divers from previous marine debris removal missions in Papahānaumokuākea have released endangered monk seals and threatened green sea turtles (James Morioka, pers. com) from entanglement in derelict fishing nets. Nets that snag on corals can cause breakage, abrasion, tissue loss, and mortality (Al-Jufaili et al., 1999; Bo et al., 2014; Mulochau et al., 2020; Patterson Edward et al., 2019; Richards and Beger, 2011; Sheehan et al., 2017; Suka et al., 2020; Valderrama Ballesteros et al., 2018). The longer these nets remain stationary on reefs, the more of a hazard they pose by having an increased likelihood of ensnaring and endangering wildlife or smothering and damaging corals.

Traveling derelict fishing nets, like the nets that moved from the atoll perimeter towards the interior of the atoll, can also pose hazards to the environments they encounter. Drifting nets can entangle migratory species, such as dolphins and sea turtles. One comprehensive review of marine debris entanglement estimated that 100,000 marine mammals died every year from entanglement or ingestion of fishing gear, mainly monofilament lines, nets, and ropes (Laist, 1997). Another review of ray and shark entanglement cited 557 animals from 26 studies, the majority of which were entangled in ghost fishing gear, or derelict fishing nets (Parton et al., 2019).

The results from our pilot study can assist in informing future net removal efforts. This study shows that nets that enter Manawai atoll in the northeast quadrant are likely moving with the prevailing winds and thus head towards the center of the atoll where they can remain stationary for years. Subsequent missions to remove derelict nets should include effort in areas where nets are known to first enter the atoll in order to minimize interactions with various reef ecosystems and preventing encounters with the critical reef habitat in the lagoon interior. In addition, focusing effort on the central interior of the atoll where nets appear to accumulate throughout the reticulated reef can maximize net removal efficiency.

While the cessation of release from the source of these conglomerate nets is ideal, a more achievable local-scale goal is to understand the movement and extent of impact nets can have on reefs to increase the benefits of removal efforts. If we use satellite tags in the future to track net movements, we will research how other industries, such as the purse seine industry, attach these monitoring buoys to their fishing nets. We also plan to return to Manawai to remove the four nets that were relocated, after which the underlying reefs where nets remained stationary can be surveyed and assessed for resulting damage. Lastly, our recent findings will inform the next removal mission, so that removal efforts can be concentrated on the reticulated reef structure in the center of the atoll, and in the northeast quadrant, where nets can be removed prior to moving across the shallow reefs towards the center.

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CRediT authorship contribution statement

Kaylyn S. McCoy: Software, Formal analysis, Writing – original draft. **Brittany Huntington:** Writing – original draft, Validation. **Tye L. Kindinger:** Formal analysis, Writing – original draft, Validation. **James Morioka:** Resources, Conceptualization, Methodology, Investigation, Writing – original draft. **Kevin O'Brien:** Resources, Conceptualization, Methodology, Investigation, Writing – original draft.

Declaration of competing interest

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

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