CHARACTERISATION OF VISITATION OF THE REMOTE CONCEPTION ISLAND NATIONAL PARK USING DAILY SATELLITE IMAGERY

R. Graham Reynolds* and Austin Cone

*Corresponding author: greynold@unca.edu

Department of Biology, University of North Carolina Asheville, USA

ABSTRACT

Conception Island is a remote island bank in the central Bahamas, the entirety of which is encompassed within the Conception Island National Park. Conception Island is of vital importance to numerous threatened and critically endangered wildlife species, but tracking visitation is considered challenging as there is no warden and not all vessels follow registration rules. To augment understanding of park visitation, we obtained daily satellite imagery from Dove CubeSat® satellites managed by the company Planet® to characterise diurnal marine vessel traffic around Conception Island between 2016 and 2021. We obtained a total of 888 observable days, which yielded 1,197 vessel detections. Using these remote observations, we were able to geolocate vessels that visited Conception Island National Park over this period, as well as estimate the length overall of each vessel to within 10 m. We found that peak visitation to the National Park occurs in the spring, a time that corresponds to when migrating songbirds arrive at the island, when the critically endangered Silver Boa is mating, when White-tailed Tropicbirds are using the island for mating, and when Green Turtles are starting to lay eggs. This study provides the first analysis of marine vessel visitation to Conception Island National Park and we believe that these data show that the park is visited far more frequently than was appreciated.

Key words: birds, boa, Caribbean, *Chilabothrus*, endangered species, protected area management, Bahamas National Trust

INTRODUCTION

Conception Island National Park (CINP) is one of 32 national parks in the Bahamas managed by the Bahamas National Trust (BNT), a non-governmental, non-profit organisation. The BNT is funded in part by the Commonwealth of the Bahamas (about 33 per cent of operating expenses; Bahamas National Trust, 2018) as well as support from individuals, members and corporate partners (Bahamas National Trust, 2020). The Bahamas National Trust oversees these 32 parks and 2.2 million acres via the legal authority vested in it by the Commonwealth of the Bahamas through an act of Parliament (Bahamas National Trust Act of 1959). Nevertheless, given the vast territory and distances of the parks from Nassau, several of these parks and protected areas (including CINP) have lacked sufficient resources for patrol, wardens or monitoring and some have been considered 'paper parks' (e.g. Knapp et al., 2011) meaning that little enforcement is possible. Such a characterisation might not be appropriate, however, as park protection and conservation enforcement are complicated and multifaceted in the Bahamas (e.g. Wise, 2014). Nevertheless, a lack of data makes conservation decision making more challenging (Chiappone & Sealey, 2000).

Established in 1978 and expanded in 2009, CINP encompasses Conception Island, Booby Cay and the South Rocks as well as the oceanic platform surrounding these islands extending out to the 100-fathom line (Figure 1). Conception Island National Park is one of only a few National Parks in the Commonwealth that encompasses an entire island bank free from development pressures. Conception Island is one of the most remote national parks in the BNT system and is of critical importance to regional wildlife. It is home to 68

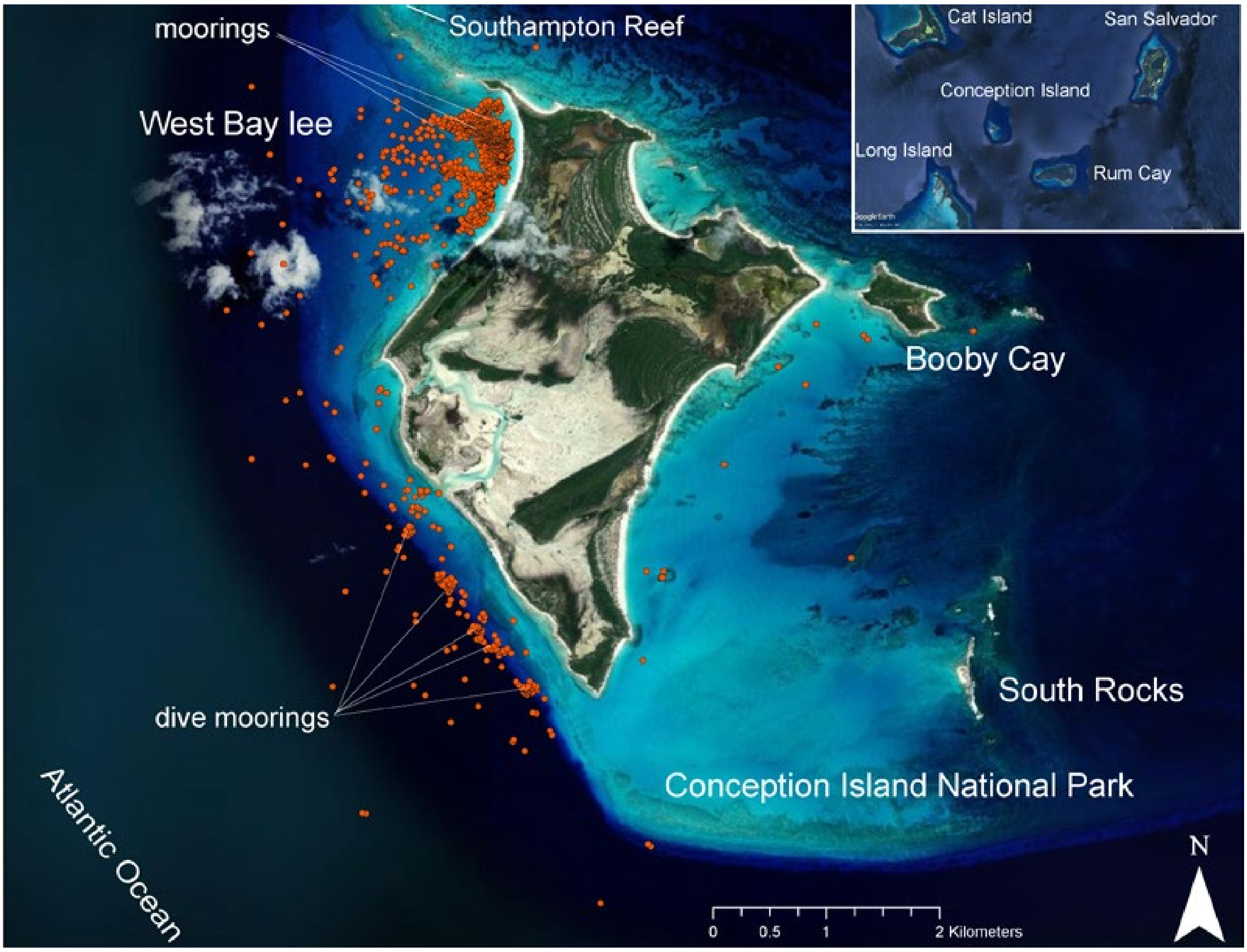

Figure 1. Map of Conception Island National Park, located in the central Bahamas Archipelago (inset). The Conception Bank is visible as the lighter blue areas, the darker blue is open ocean. Conception Island National Park extends across the bank to the 100-fathom line in all directions, which corresponds approximately to the darkest blue in the image. All 1,197 vessel locations obtained during the study are mapped, where each orange dot represents one vessel. Note that the majority, over 900 of the observations, are in the West Bay lee anchorage area. Another large proportion are moored along the dive mooring buoys along the western margin of the bank. Inset map from Google Earth, main image from ArcGIS Pro®

bird species, and hosts regionally important seabird nesting areas for species such as Audubon's Shearwater (*Puffinus lherminieri*), which might have as many as 250–500 breeding pairs present in the park (Mackin, 2007, 2015; Reynolds & Buckner, 2022; Sprunt, 1984). Conception Island is thought to have the largest White-tailed Tropicbird (*Phaethon lepturus*) nesting colony in the Bahamas, one of the largest Sooty Tern (*Onychoprion fuscatus*) colonies, and one of the largest Brown Noddy (*Anous stolidus*) colonies in the Bahamas (White, 1998). Three of the eight range-restricted bird species in the Bahamas Endemic Bird Area (BEBA) are documented from CINP (Reynolds & Buckner, 2022). White-crowned Pigeons (*Patagioenas leucocephala)* are common in CINP and are listed as Near Threatened on the IUCN Red List (BirdLife International, 2020). Because there are so many species of birds, several of which are species of concern that have robust breeding colonies, the bank is of tremendous importance to avifauna conservation. Further, CINP is home to the only population of the endemic Conception Island Bank Silver Boa (*Chilabothrus argentum*), which is listed as Critically Endangered on the IUCN Red List (Reynolds, 2017) and consists of fewer than 200 adults (Reynolds et al., 2020, 2022). Finally, CINP hosts crucial mangrove habitats which serve as nurseries for Green Turtles (*Chelonia mydas)* as well as economically important fishery species (Bjorndal et al., 2003; Serafy et al., 2003). Despite its protection as a national park, Green Turtles were previously harvested (Bjorndal et al., 2003), as are lobster, Queen Conch (*Aliger gigas*) and finfish (R. G. Reynolds, pers. obs.). Shotgun shells were found on Booby Cay in the 1990s, likely from bird hunting (Franz & Buckner, 1998; Reynolds & Buckner, 2022), and at least six used signalling flares were found in 2017, which pose a fire hazard (Reynolds et al., 2020, 2022).

Conception Island has long been a destination for sailors, with West Bay lee (Figure 1) providing the only protected harbour on the bank, and only in relatively calm sea conditions with prevailing winds. Three mooring buoys were installed in West Bay lee in 2014, one of which can accommodate ships of at least 60 m length overall (LOA; Figure 1). Visitors to the park are expected to first register their vessel with the BNT and to follow posted rules about park use (see Figure 2). Visitors are permitted to come ashore on Conception Island, but only on the beaches and never with pets (although this latter rule is frequently disregarded, R. G. Reynolds, pers. obs.). Visitors are not allowed on Booby Cay nor South Rocks, owing to their importance to bird nesting. Previously, large signs with visitation rules were deployed at strategic points along Conception Island and Booby Cay, warning visitors not to disturb wildlife. Those signs were destroyed by Hurricane Joaquin in 2015 and were subsequently replaced through a partnership between the North Carolina Zoo, the BNT and the first author RGR (Figure 2; Reynolds et al., 2020). Beyond West Bay lee, the rest of the bank can be treacherous to navigate owing to coral reef heads, sand bars and lee shores. Indeed, a famous double shipwreck of the Southampton and the Vixen in 1812, on what is now known as Southampton Reef (Figure 1), stranded 300 sailors on the island until they were rescued by a ship bound for Port Royal, Jamaica (One of the Vixen's crew, 1813). Additional private mooring buoys are located along the southern edge of the Conception Bank, the second most popular destination in CINP behind West Bay lee, owing to the excellent scuba diving available there.

Though CINP is managed by the BNT, the island is hard to oversee for several reasons: CINP has no cell phone signal, has poor marine radio signal and is rarely visited by BNT park rangers or wardens. With these disadvantages and given that vessels do not always register their visits to CINP, the BNT has not had an easy way to monitor visitation to the park, to assess visitor numbers or where visitors are going, and limited knowledge of what time of year most visitation occurs. This study sought to determine whether the use of remote sensing data obtained from satellite imagery could be used to provide a base-level understanding of CINP visitation to assist the BNT in making future management decisions, such as whether to implement more permanent and comprehensive monitoring. Specifically, some commercial companies use satellites to image portions of the Earth daily at high-resolution, a relatively new resource for non-governmental or non-corporate entities. One of these is the company Planet® (Planet Labs Inc.). Planet Labs was founded in 2010 and has more than 200 operational satellites. Planet® offers multiple services, including high-resolution real-time monitoring, high frequency mosaic base maps and high-resolution image tasking. While their image access is largely intended for corporate customers, a researcher and education access grant was available and was used for the present study.

This study is an attempt to characterise visitation and use of a remote national park in the Lucayan Archipelago using satellite imagery. Such studies could provide valuable data to assist with decision making regarding park monitoring as part of a comprehensive plan for well-managed and well-protected natural assets.

METHODOLOGY

Site description

Conception Island National Park encompasses the entirety of the Conception Island Bank, which is a partially submerged carbonate platform occupying about 102 km² and surrounded by water > 2,000 m deep on all sides. The bank is located within an imaginary polygon bounded by the larger Bahamian Islands of Cat Island to the northwest, Long Island to the southwest, Rum Cay to the southeast and San Salvador to the northeast. Conception Island Bank is dominated by Conception Island, which is 820 ha with a maximum elevation of 24 m (Lands and Surveys Department, Bahamas Government, 1972). Booby Cay (20 ha) is 250 m east of Conception Island, and the South Rocks (2.5 ha) are 2.6 km to the southeast of Conception Island. Numerous smaller emergent islets and rocks dot the bank, and the Southampton Reef projects north ~7.5 km from Conception Island then curves to the east.

Figure 2. Laws governing visitor use at Conception Island National Park. These are new signs that were installed at various locations throughout the park in 2021.

Two vessels located in West Bay lee, Conception Island National Park, Bahamas July 2015. In the foreground is a dive boat from Long Island that has made a day trip, in the background is a sailing vessel at anchor. Both vessels are in the 10-–20 m LOA class © R. Graham Reynolds.

Table 1. Description of the dataset used in the study, with explanations for how data were included or excluded from the study. A total of 1,304 days were excluded, and 888 days were included in the final dataset, out of a possible 2,192 days during the study.

Days Excluded: 1,304
2,192 possible days (1 Jan. 2016 to 31 Dec. 2021)
282 days without any imagery data
941 without a direct satellite pass or missing large areas
81 days with >50 per cent cloud cover
Total: 1,304 days excluded
Total: 888 days included
Days Included: 888
499 days with no vessels detected
78 days with some clouds and no vessels
91 days with some missing imagery and no vessels
330 days with no visibility impediments
389 days with at least one vessel
133 days with some clouds and vessels
104 days with some missing imagery and vessels
152 days with no visibility impediments

Imagery and analysis

We accessed near-daily satellite imagery of CINP from the company Planet®, granted via an Education and Research Program award. Planet uses Dove CubeSat® satellites to take images up to 3.7 m resolution in four multispectral bands (RGB and near infrared). These images are aggregated in Planet's online database, and images are interactively searchable using a map of satellite image areas (Planet Team, 2017). We searched all available imagery for the Conception Island Bank (bounded between approximately 23.8625° and 23.7910° north latitude and -75.1390° and -75.0710° west longitude) and logged daily photos from 1 January 2016, to 31 December 2021. We made note of, but excluded, days when CINP was at least 50 per cent obscured by clouds. Because we did not use satellite imagery tasking, we relied on preplanned satellite imaging sweeps and hence satellites do not make a direct overhead pass of CINP every day. So, days that did not have imagery of CINP were also noted but excluded. All retained near-daily images were downloaded in full colour at the highest resolution available within Planet's proprietary visualisation interface (Planet Team, 2017).

For each retained image, CINP was visually scanned for marine vessels starting at the northeast corner of the bank and then around the bank in a counter-clockwise pattern. Vessel locations were recorded as latitude and longitude in decimal degrees provided by Planet's pinpoint tool (Planet Team, 2017). The pinpoint was placed at the centre of each vessel observed. Length overall (LOA) in metres was obtained by measuring from bow to stern with Planet's distance measuring tool. The measuring tool's smallest increment was 10 m, so all vessels smaller than the smallest increment were marked in the 10 m category, and LOA is approximated to within 10 m. Depending on the tide and sea conditions, exposed sandbars and reefs can give the appearance of a vessel, in these cases, the area was compared to known visible sand bars and reefs on the bank (known from other images being assessed as well as previous ground truthing expeditions in 2015–2017; Reynolds & Buckner, 2022; Reynolds et al., 2022). Smaller vessels that were obviously ship tenders were not counted if they appeared to be nearly in contact with a larger vessel. Objects appearing to be vessels located in areas where vessel traffic would be unlikely (i.e. on top of very shallow reef heads) were not included. Similarly, windy days can produce whitecaps that resemble vessels. To reduce the possibility of mistaking waves for vessels, we crossed-referenced days when whitecaps appeared to be present against a database of historical wind speeds for the area using timeanddate.com. If wind speeds suggested that whitecaps would be present (generally, sustained winds >30 kts), and if the wind direction corresponded to the expected location (aspect relative to Conception Island) of whitecaps, then ambiguous observations were not counted as vessels.

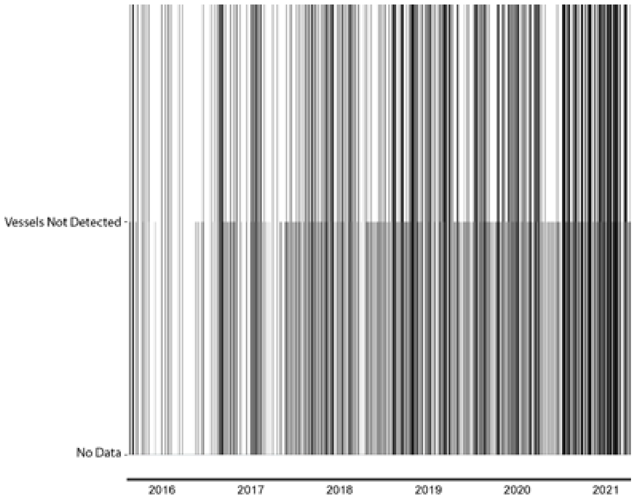

Figure 3. Distribution of imagery availability and vessel detection over the study period. White bars represent days without any imagery data (1,304), bars reaching halfway represent days when vessels were not detected (499), and bars reaching full height represent days when at least one vessel was detected (389). All bars with either imagery data, vessel data, or both are grey colored, the appearance of darker bar colors simply indicates more days are stacked closer together. Note that fewer imagery days were available towards the beginning of the study.

After parsing all images, we mapped each vessel observation onto a satellite image of CINP using ArcGIS Pro® with the '*import x,y coordinates*' tool and adjusted the size of the points. We then imported our data matrix into R v4.3.0 (R Core Team, 2023) and plotted a histogram of vessel sizes using RStudio v2023.03.1. We created a bar plot of vessel frequency per month of the year, aggregating across the six years of the study to determine when visitor numbers were highest, as well as characterise seasonal visitation patterns. We also created a boxplot comparing the LOA of vessels through each month of the year and tested for a relationship between LOA and month using a 1-way ANOVA test using the function *aov*() in R.

RESULTS

Our study period from 1 January 2016 to 31 December 2021 spans a total of 2,192 days. Of that potential period, we excluded a total of 1,304 days (Table 1; Figure 3) as 282 days did not have imagery data loaded into Planet's database, 941 days did not have a satellite pass over CINP, and 81 days were too cloudy (>50 per cent cloud cover over CINP). This left a total of 888 observable days, or 40.5 per cent of the total days of the study period. We did not detect vessels on 499 of 888 observable days (56.2 per cent; Figure 3). Of the observable days without vessels, 78 had some cloud cover, 91 had partial missing imagery and 330 had no imagery issues (Table 1). During these 888 observable days, we recorded at least one vessel present on 389 of the days (43.8 per cent; Figure 3) and documented a total of 1,197 vessels. Of the days in which vessels were detected, 133 had at least some cloud cover, 104 days had some missing satellite imagery, and 152 days had no imagery issues (Table 1).

The average vessel LOA was 17.7 m (range 10–100 m), which suggests a mean vessel size capable of open ocean travel in calm water. But the most frequent vessel observed was in the range of 10 m or less LOA (mode

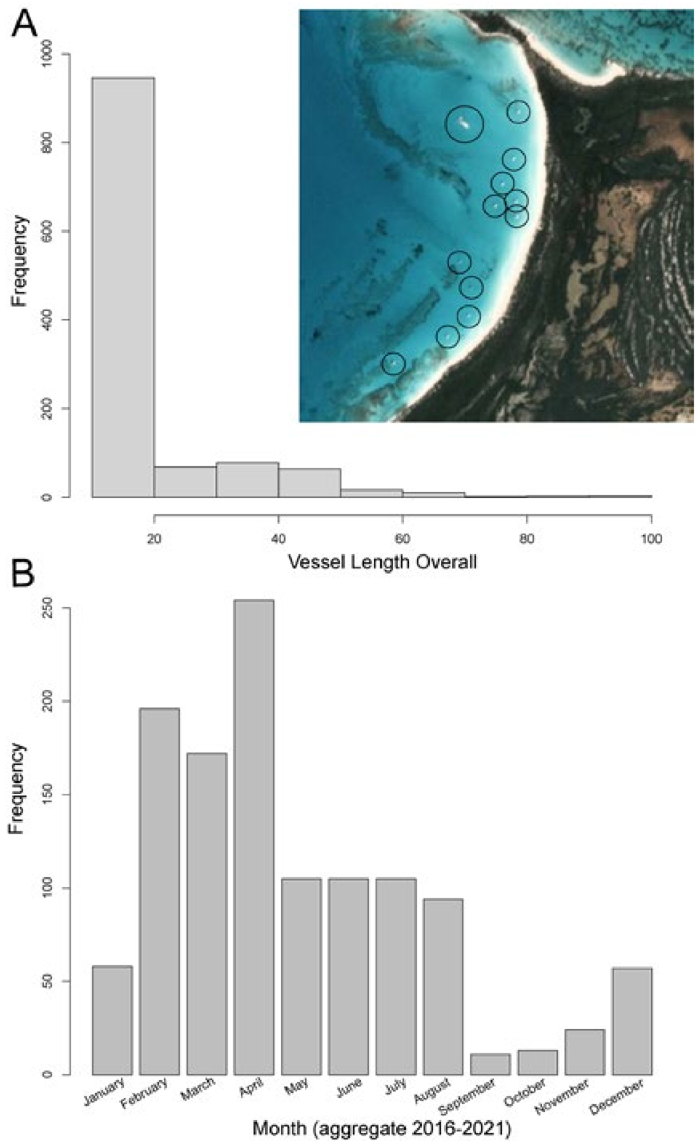

Figure 4. A) Histogram showing the frequency of vessels given their size (LOA) visiting Conception Island National Park. The inset shows relative vessel size comparisons. It is an image from Planet® from 7 February 2021 with black circles around a 40 m LOA ship at a mooring buoy in West Bay lee and 11 vessels of the 10 m LOA size class scattered in West Bay. B) Bar plot of aggregate monthly visitation to Conception Island National Park 2016–2021. Note that September and October are the peak hurricane season in the Bahamas, hence visitor numbers are expected to be low (but they are not zero).

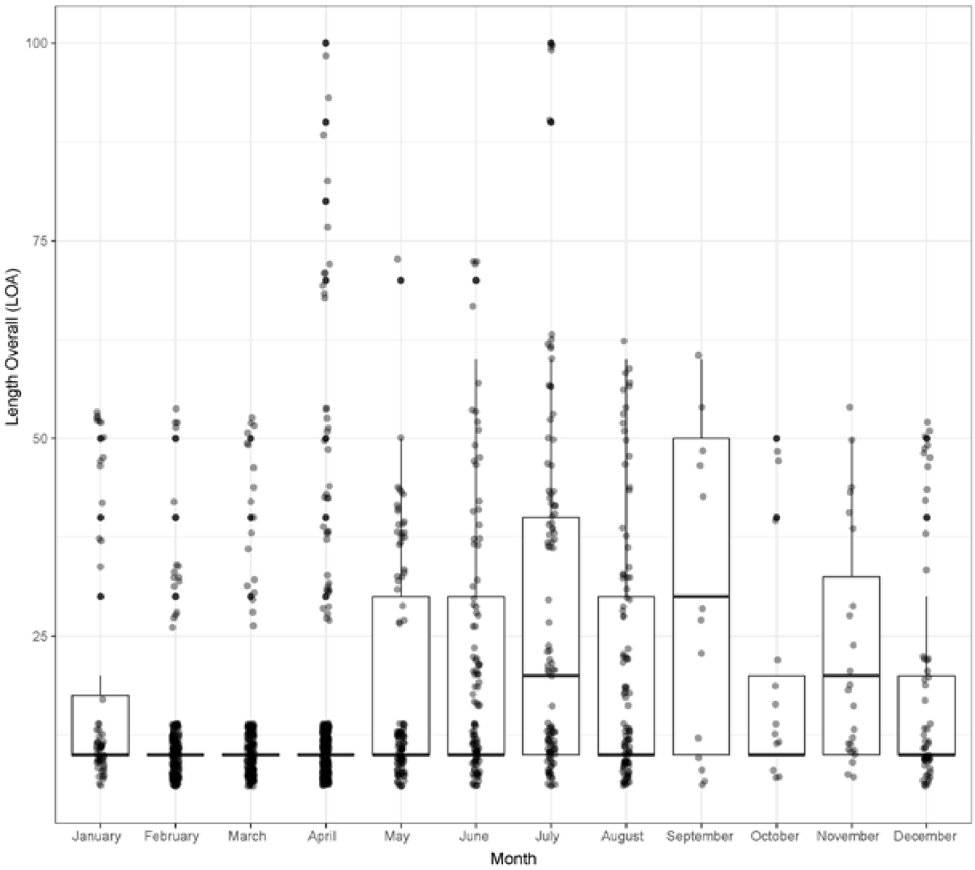

Figure 5. Box-and-whisker plot of vessel sizes (LOA) by month for Conception Island National Park. Note that the points are offset and differently coloured relative to one another to allow visualisation ('jittered').

LOA = 10 m, median LOA = 10 m; Figure 4), which represents what would be regarded as a relatively small vessel for making a trip to CINP.

Vessel detection was highest in the spring, particularly between February and April (Figure 4). Visitation to CINP was lowest during September and October, which is peak hurricane season for the area (Figure 4). Vessel LOA varied by month, with the summer months generally hosting larger vessel LOA (ANOVA = 10.9, P <0.001; Figure 5). We detected a maximum of 16 vessels in one day (18 April 2021).

Most vessels detected in CINP were observed in two core areas: in the West Bay lee of Conception Island or at the dive wall mooring buoys at the southern edge of Conception Island Bank (Figure 1). All vessels detected on the eastern side of Conception Island and near Booby Cay or South Rocks were vessels <20m LOA.

DISCUSSION

The foremost goal of this study was to characterise marine vessel traffic in Conception Island National Park to gather baseline data on visitation to the park, something that has not previously existed. This is particularly important as remote national parks, including CINP, are home to numerous threatened and endangered species (Carey et al., 2001; Reynolds & Buckner, 2022; Reynolds et al., 2022). Conception Island National Park is understudied (relative to the Exuma Cays Land and Sea Park; Chiappone & Sealey, 2000; Dahlgren, 2004) given its significance to regional wildlife, both in the Commonwealth of the Bahamas as well as the greater Lucayan Archipelago. This is starting to change with increased attention to the island bank, and new studies continue to emphasise the biodiversity significance of the park (e.g. Reynolds et al., 2016; Reynolds & Buckner, 2022). Of concern are visitor activities and visitation rates that could disrupt ecologically sensitive species that do not nest in areas with frequent human activity, such as White-tailed Tropicbirds (Walsh-McGehee, 2000). Nevertheless, CINP has and will continue to remain a treasured destination for visitors, and it is known that ecotourism, when properly managed, can be beneficial to local economies and to attitudes towards biodiversity conservation (Walpole et al., 2001; Walpole & Leader-Williams, 2002). Thus, additional signage might help to reduce visitor impacts on ecologically sensitive parts of the island, such as the north cliffs where the tropicbirds nest. Further, there could be additional mooring buoys deployed to accommodate the traffic, which we found can be over a dozen vessels a day.

Despite not having the ability to task satellites, we obtained an observation rate of 40.5 per cent, being the percentage of days in the study for which we obtained an image of the CINP that was less than 50 per cent obscured by clouds (Table 1). Of these 888 observable days, 482 (54.3 per cent) had no imagery missing and minimal cloud cover, while 406 had some cloud cover and some missing imagery. Clouds can certainly obscure vessels, and some of these observable days had partial missing imagery, which means that a satellite did not pass completely over CINP, or a section of the image was missing. Therefore, it is likely that our approach is conservative, in that we have almost certainly undercounted vessels in CINP.

Our data showed a surprisingly high level of marine vessel visitation to CINP. Dozens of vessels visit the island every month, and an average of 240 vessels per year are mooring on the bank. Further, most visitation occurs in the spring, a season when migratory songbirds arrive to the island and White-tailed Tropicbirds are mating. Visitation drops off during the peak of the hurricane season, as expected, but surprisingly does not fall to zero. This concurs with observations by RGR, who observed one sailing vessel in CINP in October 2015 just one week after the passage of Hurricane Joaquin, a category 4 major hurricane. The most frequent vessel observed was in the range of 10–20 m LOA (mode LOA = 10 m, median LOA = 10 m), which represents what would be regarded as a relatively small vessel for making a trip to this region. This category (10 m LOA) most likely includes a combination of small sailing vessels, outboard-powered fishing and pleasure boats, and small craft known as vessel tenders used to make trips back and forth from a larger ship. Outboard-powered centre-console boats can easily reach CINP from Long Island or Cat Island in less than two hours in calm seas, and many sailing vessels that cruise in the Bahamas are in the range of 20 m LOA (R. G. Reynolds, pers. obs.). Given the imagery available, a precise determination of vessel LOA is challenging, although we note that a difference between a vessel 5 m LOA and 15 m LOA is a significant difference with regard to offshore seaworthiness. This limitation means that we are not fully able to determine vessel types at LOA of 10 m or less. But smaller vessels probably overestimate actual visitor numbers, as it is likely that the presence of both large and small LOA vessels on a given day represents both a mothership and its tender(s). Indeed, on 8 February 2021, we documented a mothership with at least 12 skiffs or small sailing craft operating in West Bay lee (Figure 4). Hence, we expect that we are overcounting vessels relative to independent operators, but there is no way to consistently parse between a mothership and its tender with the resolution offered in the Planet images unless the vessels appear to be moored together. We also documented several ships up to 100 m LOA, which is the size of a superyacht or small cruise ship that can carry dozens of guests and crew. The first author RGR has visually observed one such vessel in July 2017, a superyacht carrying a helicopter that moored for 24 hours in West Bay lee.

All vessels detected on the eastern side of Conception Island and near Booby Cay or South Rocks were vessels <20 m LOA. This is a shallow water and treacherous operating area, but also happens to be a good area for marine recreation activities and bird watching. Vessels would not be expected to moor there, as the prevailing winds (SSE to NNW) make the island a dangerous lee shore (R. G. Reynolds, pers. obs.). Nevertheless, smaller craft such as vessel tenders could navigate this side of the bank. Most vessels were observed near the mooring buoys in West Bay lee and the dive wall (Figure 1). These are the safest anchorages, but also provide ready access to recreational opportunities such as scuba diving, snorkelling and access to the island itself. Anecdotal reports suggest that fishing and lobstering also take place in these areas, even though it is illegal to do so. Given these data, a fruitful path might be the extension of a recreational plan for CINP, similar to what has been accomplished elsewhere in the Bahamas such as the Exuma Cays Land and Sea Park and Abaco National Park (Eadens et al., 2009).

We noted a few areas that could be improved in future studies. The measuring tool within Planet's software gives a rough approximation of vessel LOA but is probably only accurate to within 5–10 m and there is no consistent way to verify these distances against known landmarks with enough precision to improve estimates of LOA. Another weakness is that images are limited to one photo per day, hence vessels that arrive or depart from CINP outside of the imaging time are not detectable. Finally, it is known that some vessels visit during the nighttime, presumably to conduct illicit activity (Reynolds et al., 2020). Hence, other technologies such as shore-based radar or underwater sound traps could provide a more comprehensive approach to park monitoring. Despite the limitations of the satellite imagery we used, we found that the use of Planet's imagery database can provide a highly useful estimate of remote park visitation.

ACKNOWLEDGEMENTS

We thank the company Planet® for awarding RGR a Research and Education Grant to access satellite data. This work was supported by the National Geographic Society (to RGR) and by the Reynolds Lab at the University of North Carolina Asheville.

ABOUT THE AUTHORS

R. Graham Reynolds is an Associate Professor at the University of North Carolina Asheville. His research is focused on biodiversity in the Caribbean, conservation and population genetics, and vertebrate biology. He is a lifetime member of the Bahamas National Trust. https://orcid.org/0000-0002-0056-8304

Austin Cone was an undergraduate student at the University of North Carolina Asheville and a researcher in the Reynolds Lab. He is interested broadly in wildlife and species conservation.

REFERENCES

Bahamas National Trust. (2018). *Bahamas National Trust strategic plan 2018–2022*. Available at www.bnt.bs.

Bahamas National Trust. (2020). *Bahamas National Trust 2020 impact report*. Available at: www.bnt.bs.

BirdLife International. (2020). Patagioenas leucocephala. The IUCN Red List of Threatened Species 2020: e.T22690229A178283762. https://dx.doi.org/10.2305/IUCN.UK.2020-3.RLTS.T22690229A178283762.en.

Bjorndal, K. A., Bolten, A. B., & Chaloupka, M. Y. (2003). Survival probability estimates for immature green turtles *Chelonia mydas* in the Bahamas. *Marine Ecology Progress Series*, 252, 273–281.

Carey, E., Buckner, S. D., Alberts, A. C., Hudson, R. D., & Lee, D. (Eds.). (2001). *Protected areas management strategy for Bahamian terrestrial vertebrates: iguanas and seabirds.* Apple Valley, Minnesota: IUCN/SSC Conservation Breeding Specialist Group.

Chiappone, M., & Sealey, K. M. S. (2000). Marine reserve design criteria and measures of success: lessons learned from the Exuma Cays Land and Sea Park, Bahamas. *Bulletin of Marine Science*, 66, 691–705.

Dahlgren, C. P. (2004). Bahamian marine reserves—past experience and future plans. In J. Sobel & C. Dahlgren (Eds.). *Marine reserves: a guide to science, design, and use* (pp. 268–286). Washington, DC: Island Press.

Eadens, L. M., Jacobson, S. K., Stein, T. V., Confer, J. J., Gape, L., & Sweeting, M. (2009). Stakeholder mapping for recreation planning of a Bahamian National Park. *Society and Natural Resources*, 22, 111–127.

Franz, T., & Buckner, S. D. (1998). Preliminary survey of the herpetofauna of Conception Island, Bahamas. In T. K. Wilson (Ed.) *Proceedings of the seventh symposium on the natural history of the Bahamas* (pp. 37–40). San Salvador, Bahamas: Gerace Research Centre.

Knapp, C. R., Iverson, J. B., Buckner, S. D., & Cant, S. V. (2011). Conservation of amphibians and reptiles in the Bahamas. In A. Hailey, B. Wilson, & J. Horrocks (Eds.) *Conservation of Caribbean island herpetofaunas volume 2: regional accounts of the West Indies* (pp. 53–87). Brill.

Lands and Surveys Department, Bahamas Government. (1972). *Bahamas, Conception Island, Sheet 1. Scale 1:25,000*. Nassau, Bahamas: Lands and Surveys Department.

Mackin, W. A. (2007). Conservation of Audubon's Shearwater in the Bahamas: status, threats, and practical solutions. *Proceedings of the 12th Symposium on the Natural History of The Bahamas*, 71–79. Available at: https://www.geraceresearchcentre.com/12thNatHist.html.

Mackin, W. A. (2015). Current and former populations of Audubon's Shearwater (*Puffinus lherminieri*) in the Caribbean region. *The Condor*, 118, 655–673.

One of the Vixen's Crew. (1813). *A narrative of the capture of the United States brig Vixen, of 14 guns, by the British frigate Southampton; and the subsequent loss of both vessels, on a reef of rocks, off Conception Island*. New York: Printed and sold at the Office of "The War.

Planet Team. (2017). *Planet application program interface: in space for life on Earth*. San Francisco, CA. https://api.planet.com.

R Core Team. (2023). *R: a language and environment for statistical computing*. Vienna, Austria: R Foundation for Statistical Computing. https://www.R-project.org/

Reynolds, R. G. (2017). *Chilabothrus argentum*. *The IUCN Red List of Threatened Species* 2017: e.T118470875A118470877. https://dx.doi.org/10.2305/IUCN.UK.2017-3.RLTS.T118470875A118470877.en.

Reynolds, R. G., & Buckner, S. D. (2022). Characterization of the bird diversity of Conception Island National Park, The Bahamas. *Journal of Caribbean Ornithology*, 36, 17–25.

Reynolds, R. G., Puente-Rolon, A. R., & Geneva, A. J. (2022). Natural history and morphometrics of the newly discovered and critically endangered Silver Boa (*Chilabothrus argentum*; Squamata; Boidae). *Caribbean Naturalist*, 88, 1–20.

Reynolds, R. G., Puente-Rolón, A. R., Aviles-Rodriguez, K. J., Geneva, A. J., & Herrmann, N. C. (2016). Discovery of a remarkable new boa from the Conception Island Bank, Bahamas. *Breviora*, 549, 1–19.

Reynolds, R. G., Smith, D., Buckner, S. D., Cant-Woodside, S., Gape, L., Deane, G., Miller, P., & Byers, O. (Eds). (2020). *Conception Bank Silver Boa species conservation planning workshop, final report.* Apple Valley, MN: IUCN SSC Conservation Planning Specialist Group.

Serafy, J. E., Cowen, R. K., Paris, C. B., Capo, T. R., & Luthy, S. A. (2003). Evidence of blue marlin, *Makaira nigricans*, spawning in the vicinity of Exuma Sound, Bahamas. *Marine & Freshwater Research*, 54, 299–306.

Sprunt, A. (1984). The status and conservation of seabirds of the Bahama Islands. In J. P. Croxall, P. G. H. Evans, & R. W. Schreiber (Eds.) *Status and conservation of the world's seabirds* (pp.157–168). Technical Publication No. 2. Cambridge, UK: International Council for Bird Preservation.

Walpole, M. J., & Leader-Williams, N. (2002). Tourism and flagship species in conservation. *Biodiversity and Conservation*, 11, 543–547.

Walpole, M. J., Goodwin, H. J., & Ward, K. G. R. (2001). Pricing policy for tourism in protected areas: lessons from Komodo National Park, Indonesia. *Conservation Biology*, 15, 218–227.

Walsh-McGehee, M. (2000). Status and conservation priorities for White-tailed and Red-billed tropicbirds in the West Indies. In *Status and conservation of West Indian Seabirds. Special publication* 1(pp. 31–38).

White, A. W. (1998). *A birder's guide to the Bahama Islands (including Turks and Caicos)*. Colorado Springs, CO.: American Birding Association Inc.

Wise, S. P. (2014). Learning through experience: Non-implementation and the challenges of protected area conservation in The Bahamas. *Marine Policy*, 46, 111–118.

RESUMEN

Conception Island es un remoto banco insular de las Bahamas centrales, cuya totalidad está incluida en el Parque Nacional de Conception Island. La isla Concepción es de vital importancia para numerosas especies de fauna amenazadas y en peligro crítico de extinción, pero el seguimiento de las visitas se considera un reto, ya que no hay guardas y no todas las embarcaciones siguen las normas de registro. Para aumentar la comprensión de las visitas al parque, obtuvimos imágenes satelitales diarias de los satélites Dove CubeSat® gestionados por la empresa Planet® para caracterizar el tráfico diurno de embarcaciones marinas alrededor de la isla Concepción entre 2016 y 2021. Obtuvimos un total de 888 días observables, que arrojaron 1.197 detecciones de embarcaciones. Gracias a estas observaciones remotas, pudimos geolocalizar las embarcaciones que visitaron el Parque Nacional de la Isla de la Concepción durante este periodo, así como estimar la eslora total de cada embarcación con una precisión de 10 m. Descubrimos que el pico de visitas al Parque Nacional se produce en primavera, una época que coincide con la llegada a la isla de las aves cantoras migratorias, el apareamiento de la boa plateada, una especie en peligro crítico de extinción, el apareamiento de los pájaros tropicales de cola blanca y el inicio de la puesta de huevos de las tortugas verdes. Este estudio proporciona el primer análisis de las visitas de embarcaciones marinas al Parque Nacional de la Isla de la Concepción y creemos que estos datos demuestran que el parque es visitado con mucha más frecuencia de lo que se apreciaba.

RÉSUMÉ

L'île de la Conception est un banc d'îles isolé au centre des Bahamas, dont la totalité est comprise dans le parc national de l'île de la Conception. L'île de la Conception est d'une importance vitale pour de nombreuses espèces sauvages menacées et en danger critique d'extinction, mais le suivi de la fréquentation est considéré comme difficile car il n'y a pas de gardien et tous les navires ne respectent pas les règles d'enregistrement. Pour mieux comprendre la fréquentation du parc, nous avons obtenu des images satellites quotidiennes des satellites Dove CubeSat® gérés par la société Planet® pour caractériser le trafic maritime diurne autour de l'île de la Conception entre 2016 et 2021. Nous avons obtenu un total de 888 jours observables, qui ont donné lieu à 1 197 détections de navires. Grâce à ces observations à distance, nous avons pu géolocaliser les navires qui ont visité le parc national de l'île de la Conception au cours de cette période, ainsi qu'estimer la longueur totale de chaque navire à 10 m près. Nous avons constaté que le pic de fréquentation du parc national a lieu au printemps, une période qui correspond à l'arrivée des oiseaux chanteurs migrateurs sur l'île, à l'accouplement du boa argenté, une espèce en danger critique d'extinction, à l'utilisation de l'île par le carouge à queue blanche pour s'accoupler et au début de la ponte des tortues vertes. Cette étude fournit la première analyse de la fréquentation du parc national de l'île de la Conception par les navires et nous pensons que ces données montrent que le parc est visité bien plus fréquemment qu'on ne le pensait.

SHORT COMMUNICATION: CAUSES OF SECONDARY FOREST LOSS IN A LOWLAND RAINFOREST OF NIGERIA

Farhan Jimba Moshood* and Samuel Olalekan Olajuyigbe

* Corresponding author: moshoodfarhan@gmail.com

Department of Forest Production and Products, University of Ibadan, Ibadan, Nigeria

ABSTRACT

The increasing human population which promotes the conversion of secondary forests into other land use types has resulted in the decrease of forest areas in Nigeria. This study examined the causes of secondary forest loss in Osho Forest Reserve, Nigeria. Changes in Land Use Land Cover (LULC) were assessed using Landsat 5 TM and Landsat 8 OLI/TC images for four timelines over a period of 38 years (1984, 2013, 2017 and 2022). Results showed an increase in area of plantations, bare land and farmland, leading to a decrease in secondary forest cover. Farmland increased from 731 ha to 859 ha at the rate of 3.7 ha yr^{-1}, bare land increased from 314 ha to 523 ha at 5.5 ha yr^{-1}, plantations increased from 1,105 ha to 1,495 ha at 10.3 ha yr^{-1}, while secondary forest drastically reduced from 1,132 ha to 405 ha at 19.1 ha yr^{-1}. At this rate, secondary forest is estimated to be lost in the study area by 2050.. Osho Forest Reserve requires immediate management interventions driven by updated laws and policies, silvicultural treatment, community engagement and ecosystem rehabilitation. In addition, implementation of sustainable forest management would enhance secondary forest recovery.

Key words: Osho Forest Reserve, remote sensing, plantation, sustainable forest management, silvicultural intervention

INTRODUCTION

In Nigeria, the forest reservation system was officially created in 1937, when approximately 20–25 per cent of the rainforest was placed under reservation and protected by enactment of gazettes. The aims were to maintain biological diversity, enhance hydrological processes, improve nutrient cycling, control soil erosion, conserve wildlife and improve air and water quality (Olajuyigbe, 2018). These forest reserves are governed by various laws and regulations which include the National Forest Policy, the Forestry Act of 1956 and state-specific forest laws (Edet et al., 2011). These legal frameworks establish rules for activities within forest reserves, emphasising conservation, sustainable management and restricted land use (Enuoh & Bisong, 2015). Forest reserves also contribute to socioeconomic growth and development, providing timber and non-timber forest products (NTFPs).

However, overexploitation of forest resources and land use change have resulted in deforestation and degradation of the reserves. The situation has been exacerbated by weak and outdated forest laws and policies, increased urbanisation and infrastructural development, and population growth. Hence, it is estimated that over 60 per cent of the country's forest estate has been lost to anthropogenic factors (Akpan-Ebe, 2017; Ancha et al., 2021; DeFries et al., 2010). Most forest reserves have become secondary regrowth which are further threatened by pressures from farmland encroachment, urbanisation and tree crop plantation establishment. The loss of secondary forests in the rainforest region of Nigeria would have devastating consequences on flora, fauna and socioeconomic activities of local communities (Fagariba et al., 2018).

Secondary forests, which represent approximately 90 per cent of the tropical forests in West Africa, are natural vegetation, which are recovering mainly through

 10.2305/IUCN.CH.2023.PARKS-29-2FJM.en

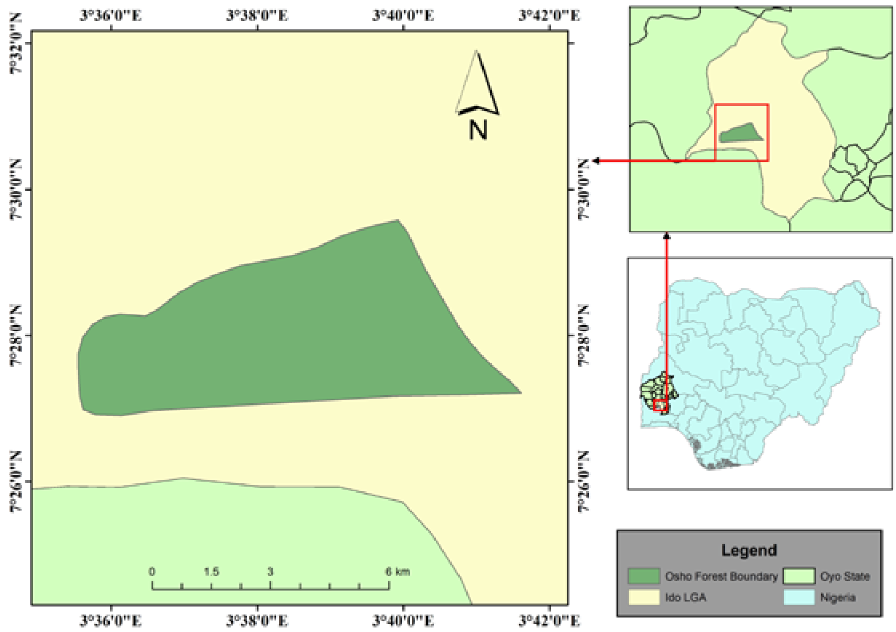

Figure 1. Map of Osho Forest Reserve (inset: maps of Nigeria, Oyo state and Ido local government area)

natural processes, after serious anthropogenic and/or natural disturbances (Chokkalingam & de Jong 2001; Schroeder et al., 2010). Secondary forests provide habitats for plant and animal species, some of which are threatened and endangered. Loss of secondary forest increases the risk of soil erosion, flooding, decreased water quality, and increased sedimentation in rivers and streams (Schroeder et al., 2010; Zeraatpishe et al., 2013). Nevertheless, the conversion of secondary forests to other land uses, such as monoculture plantations and farmlands, is usually seen as a more profitable option than leaving the land in its natural state (Wineman et al., 2021). Hence, large areas of secondary forest are being cleared for non-forest use in the lowland rainforest of Nigeria (Oluwajuwon et al., 2021). This is due to factors such as changes in government policies to promote agricultural expansion, land tenure issues, and lack of enforcement of environmental regulations. In addition, the rapid population growth has increased the pressure on land resources, resulting in increased plantation establishment and encroachment of farmlands into forest reserves (Oyetunji et al., 2020).

Previous studies have shown the increasing levels of conversion of natural forests to other land use types in different parts of the world. For instance, tropical forests were the primary source of new agricultural lands in the 1980s and 1990s, when more than 80 per cent of farmlands were established in the forests (Gibbs et al., 2010). Sanara et al. (2014) showed that farmland expansion was responsible for severe forest loss in Ratanakiri Province, Cambodia. Plantation establishment promoted plant invasions and hindered the survival of endemics in Central Chile and Chilean Patagonia (Andreas et al., 2017) and plantation establishment caused substantial loss of natural forests between 2000 and 2016 in South Central Chile (Altamirano et al., 2020).

Empirical information on the loss of secondary forest cover in comparison to the expansion of other land use types would assist in the development of strategies necessary for their long-term protection and sustainability in Nigeria. In this study, satellite images were used to assess the drivers of secondary forest loss in Osho Forest Reserve, southwest Nigeria.

MATERIALS AND METHODS

Study area

Osho Forest Reserve is one of the major reserves in southwest Nigeria. It is located in Ido Local Government Area of Oyo State, Nigeria (Figure 1). It covers an area of 3,500 ha which was reduced from 5,180 ha, by a 1951 Amendment Order (Azeez et al., 2017; Olayode, 2019). The climate is characterised by two distinct wet seasons, which occur from May to July and September to November, and a major dry season between December and March. The forest contains important indigenous trees such as *Terminalia* spp, *Treculia africana* and *Triplochiton scleroxylon* and exotic species such as *Tectona grandis* and *Gmelina arborea*.

Table 1. Satellite images used in the study

SN	Landsat type	Date	Spatial resolution (m)	Path/row
1	Landsat 5 (TM)	1984	30	191/55
2	Landsat 8 (OLI/TC)	2013	30	191/55
3	Landsat 8 (OLI/TC)	2017	30	191/55
4	Landsat 8 (OLI/TC)	2022	30	191/55

Table 2. Land Use Land Cover classes in Osho Forest Reserve, southwest Nigeria

LULC classes	Description
Secondary forest	Land with vegetation such as trees and shrubs re-growing after natural or anthropogenic disturbances
Plantation	Land dominated by tree stands raised artificially. These include *Tectona grandis, Gmelina arborea, Anogeissus leiocarpus and Tetrapleura tetraptera*
Farmland	Land used for agricultural production including arable crops, permanent crops, pastures and heterogeneous agricultural areas
Bare land	Land not under agricultural use and with no vegetation such as degraded land, bare ground, rocks and quarry-despoiled lands

Table 3. Land Use Land Cover area and rate of change in Osho Forest Reserve, southwest Nigeria (1984–2022)

	1984		2013		2017		2022		
LULC	Area (ha)	(%)	Area (ha)	(%)	Area (ha)	(%)	Area (ha)	(%)	Rate (ha yr-1) 1984–2022
Farmland	731	22.3	987	30.1	1062	32.3	859	26.2	+3.7
Bare land	314	9.8	329	10.0	404	12.3	523	15.9	+5.5
Secondary forest	1132	34.4	1053	32.1	795	24.3	405	12.4	-19.1
Plantation	1105	33.6	914	27.8	1021	31.2	1495	45.5	+10.3

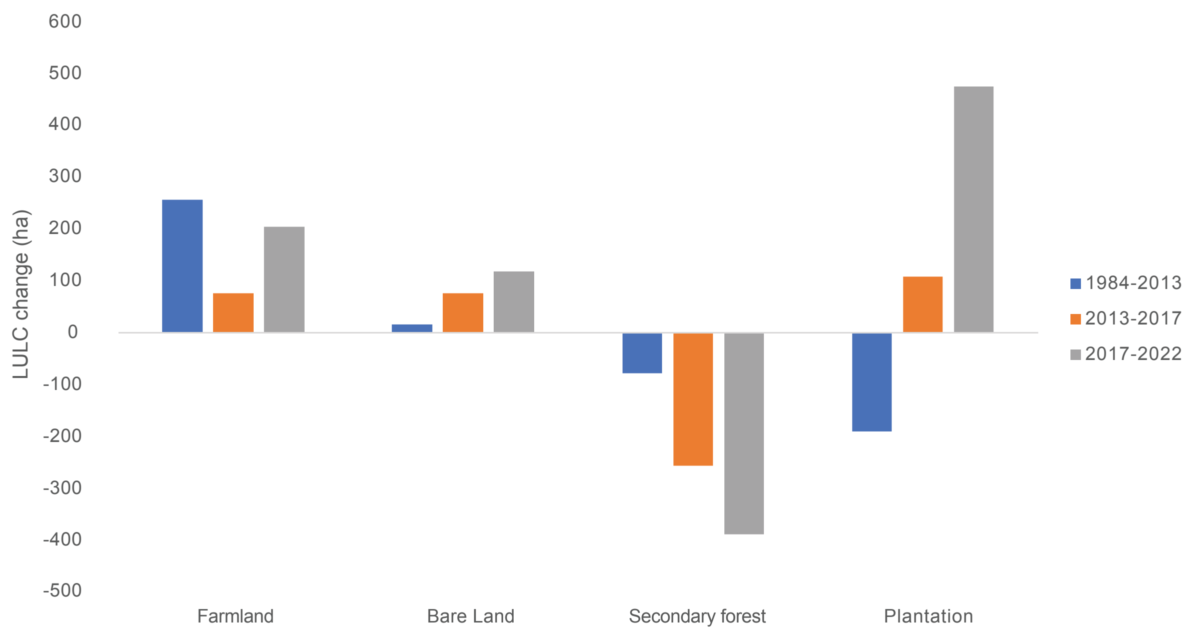

Figure 2. Land Use Land Cover Change between 1984 and 2022 in Osho Forest Reserve, Southwest Nigeria

Satellite imagery

Landsat 5 TM and Landsat 8 OLI/TC were acquired and processed to determine the land use and land-cover changes in Osho Forest Reserve at four timelines over 38 years (1984, 2013, 2017 and 2022) (Table 1).

Trend analysis

The Land Use Land Cover (LULC) was determined using equation1.

$\Delta LULC = L_2 - L_1$ .... (1)

Where L_2 (ha) = Land Use/Land Cover (final year); L_1 (ha) = Land Use/Land Cover (initial year)

Rate of change

The rate of change in LULC was calculated using equation 2.

$R_{t\,=}[(L_2 - L_1) \times {}^{1}\!/_{t})] \times 100$ .... (2)

Where L_2 (ha) = Land Use/Land Cover (final year); L_1 (ha) = Land Use/Land Cover (initial year) and t (year) = periodic interval.

Land Use Land Cover classification

Based on the description of Anderson (1976), the LULC classes identified in the study area were secondary forest, plantation, farmland and bare land (Table 2).

RESULTS

The extent and rate of change of LULC classes between 1984 and 2022 are shown in Table 3 and Figure 2. In 1984, farmland covered 731.7 ha (22.3 per cent), bare land covered 314.5 ha (9.6 per cent), plantation covered 1,105.3 ha (33.7 per cent), while secondary forest covered 1,132.2 ha (34.5 per cent). By 2013, farmland had increased to 987.4 ha (30.1 per cent), bare land increased to 329 ha (10 per cent), while secondary forest (1053.3 ha or 32.1 per cent) and plantation (914.0 ha or 27.8 per cent) were reduced in the reserve. However, by 2017, plantation cover increased (1021.7 ha or 31.1 per cent), alongside farmland area (1062.0 ha or 32.3 per cent) and bare land (404.7 ha or 12.3 per cent); while secondary forest (795.2 ha or 24.2 per cent) continued to decline. By 2022, the extent of farmland, bare land and plantation were 859.2 ha (26.2 per cent), 523.1 ha (15.9 per cent) and 1495.5 ha (45.5 per cent), respectively. On the other hand, secondary forest cover had reduced to 405.8 ha (12.4 per cent). Over the 38-year period, farmland, bare land and plantation increased by 3.4 ha yr^{-1}, 5.5 ha yr^{-1} and 10.3 ha yr^{-1}, respectively, while secondary forest decreased by 19.1 ha yr^{-1} (Table 3). Although, there was an initial decrease in plantation area (1984 to 2013), it had the highest positive rate of increase. Secondary forest would be lost entirely by 2050 and largely replaced with plantation forest if the current trend persists.

DISCUSSION

Anthropogenic factors were observed to have severely shifted the reserve from its pristine state, with the LULC classes indicating a disturbed forest ecosystem. Plantation establishment was a primary driver of secondary forest loss. Olajuyigbe (2018) indicated that natural vegetation was being replaced with exotic tree species plantations in an effort to replant the country's degraded rainforest landscape. Similarly, Adeyemi and Ibrahim (2020) found that plantation crops were being established to support timber production, while some forest reserves had become grazing grounds for livestock. This appears to also be the case in Osho Forest Reserve with close to half of the land area presently covered with monocultures of exotic species like *Tectona grandis* and *Gmelina arborea*, and patches of indigenous species plantations of *Anogeissus leiocarpus* and *Tetrapleura tetraptera*. Furthermore, the forest reserve shares boundaries with eight rural communities that depend on forest land for farming activities, wood extraction and charcoal production. The situation is further worsened by obsolete forest laws and policies, inadequate monitoring, and weak technical capacity among forest managers (Olayode, 2019).

Agricultural expansion continues to be implicated as a cause of secondary forest loss in the lowland rainforest region of Nigeria. For example, an increase in farmland area with a corresponding decrease in secondary forest has been reported across southwest Nigeria in Shasha Forest Reserve (Adeyemi & Oyeleye, 2021); Ogbese Forest Reserve (Oluwajuwon et al., 2021); Gambari Forest Reserve (Adedeji et al., 2015); Ijaiye Forest Reserve (Phillips & Ceesay, 2020); Okeluse Forest Reserve (Adeyemi & Olowo, 2022) and Oba Hills Forest Reserve (Adeyemi & Ayinde, 2022). Oyo State is one of the leading agrarian states in Nigeria with approximately 400,000 smallholder farmers (Atser et al., 2019). Hence, the high demand for farmland has led to increased encroachment of forest reserves in the state (Azeez et al., 2017; Haastrup et al., 2020; Oladoye, 2019). In addition, the renewed interest of the state government in agriculture production has led to the degazettment and conversion of parts of forest reserves to large-scale commercial farms.

The expansion of bare lands has serious ecological implications, including habitat loss, land vulnerability to erosion, loss of ecosystem resilience, and decreased ecosystem service provision. The advancement of bare land area threatens the ecological health of the Osho

Farmland Cultivated for Yam in Osho Forest Reserve © Farhan Jimba Moshood

Forest Reserve, as it was observed to increase in size by about 5.5 ha, annually. Bare land expansion has also been observed in forests of the Zurgurma Sector of Kainji Lake National Park (Adeyemi & Ibrahim, 2020) and Andoni LGA, Rivers State Nigeria (Eludoyin et al., 2019).

The future LULC estimates revealed a continuous decline in secondary forest with increases in other land uses, especially plantations. By 2050, secondary forest would have been completely replaced by plantations and other land use types. Similar trends have been reported for other secondary forests in the region. For instance, Phillips and Ceesay (2020) noted that trees in Ijaiye Forest Reserve may last for only 15 years, while Adeyemi and Olowo (2022) estimated that secondary forests in Okeluse Forest Reserve would be completely lost before 2026. Also, Adeyemi and Ayinde (2022) noted that the secondary forests in Oba Hills Forest Reserve may be completely degraded before 2040.

Artificial regeneration through direct tree planting and the taungya agroforestry system are viable alternatives for rehabilitation of forest reserves. Taungya is a system which involves growing annual crops temporarily with trees, during the early phase of plantation establishment. It has been successfully implemented in various reforestation efforts (Appiah et al., 2020; Chamshama et al., 1992). Some of the indigenous and exotic tree species presently in Osho Forest Reserve were established through the taungya system. Azeez et al. (2017) examined the performance of the taungya system in the reserve and affirmed that it contributed positively to the promotion of forest conservation. However, constraints such as lack of technical support, inadequate funding and lack of credit facilities were major impediments to its successful implementation. If these constraints are adequately addressed, assisted natural regeneration and other agroforestry practices may potentially be used to enhance indigenous tree species recovery in Osho Forest Reserve.

The challenges related to ineffective forest management strategies and conflicts between custodians of government forest reserves and farmers have to be addressed. Hence, legal constraints such as limitations on land clearing, farming and commercial activities within and around forest reserves have to be strategically resolved. Interventions such as enhanced law enforcement, community engagement, reforestation and rehabilitation projects, policy reforms, and education and awareness campaigns would be beneficial in achieving ecosystem recovery (Azeez et al., 2010; Phalan & Hajjar, 2007).

The use of remotely sensed data is essential for monitoring trends in LULC change and when combined with sociocultural information helps to identify the drivers of forest cover loss. This information is critical in tropical countries like Nigeria, where deforestation rates are high and secondary forest recovery is vital in initiatives such as landscape restoration and biodiversity conservation (Altamirano et al., 2020).

Teak Plantation in Osho Forest Reserve © Farhan Jimba Moshood

CONCLUSION AND RECOMMENDATION

The forest reserve requires immediate management interventions (such as assisted natural regeneration, enhanced law enforcement, community engagement and rehabilitation) to restore its ecological processes and functions. It is essential to improve land tenure security as this will allow small-scale farmers to practise sustainable land management. In addition, it is essential to build the capacity of forestry officials and communities in strategies that would promote natural forest regeneration as a favourable alternative to plantation establishment in the lowland rainforest of Nigeria.

ABOUT THE AUTHORS

Farhan Jimba Moshood holds a Master's degree in Forest Biology and Silviculture from the University of Ibadan, Nigeria. His research interests include forest ecology, biodiversity assessment and conservation, forest restoration and rehabilitation, climate change mitigation and adaptation and application of remote sensing and GIS. ORCID: 0000-0003-1009-746X.

Samuel Olalekan Olajuyigbe (PhD) is a Senior Lecturer in the Department of Forest Production and Products, University of Ibadan, Nigeria. He is an expert in tropical forest ecology, silviculture, forest restoration and rehabilitation. ORCID: 0000-0001-9513-3567.

REFERENCES

Adedeji, O. H., Tope-Ajayi, O. O. & Abegunde, O. L. (2015). Assessing and predicting changes in the status of Gambari Forest Reserve, Nigeria using remote sensing and GIS techniques. *Journal of Geographic Information System*, 7, 301–318.

Adeyemi, A. A. & Ayinde, M. O. (2022). Evaluation of land-use and land-cover changes in Oba Hills Forest Reserve, Osun State, Nigeria. *Forestist*, 72(2), 137–148.

Adeyemi, A. A. & Ibrahim, T. M. (2020). Spatiotemporal analysis of land-use and land-cover changes in Kainji Lake National Park, Nigeria. *Forestist*, 70(2), 105–115.

Adeyemi, A. A. & Olowo, G. E. (2022). Evaluation of forest-cover dynamics and its drivers in Okeluse Forest Reserve, Ondo State, Nigeria. J*ournal of Agriculture and Environment*, 18(1), 107–125.

Adeyemi, A. A. & Oyeleye, H. A. (2021). Evaluation of land-use and land-cover changes cum forest degradation in Shasha Forest Reserve, Osun State, Nigeria using remote sensing. Tanzania *Journal of Forestry and Nature Conservation*, 90(2), 27–40.

Akpan-Ebe, I. N. (2017). Restoration in Nigeria: history, current practice and future perspectives. *Reforesta,* 3, 105–115.

Altamirano, A., Miranda, A., Aplin, P., Carrasco, J., Catalán, G., Cayuela, L., Fuentes-Castillo, T., Hernández, A., Martínez-Harms, M. J., Peluso, F., … & Di Bella, C. (2020). Natural forests loss and tree plantations: large-scale tree cover loss differentiation in a threatened biodiversity hotspot. *Environmental Research Letters*, 15, 124055.

Ancha, P. U., Verinumbe, I., Jande, J. A. & Abakpa, S. O. (2021). Assessment of the impact of urbanization on forest resources in Otukpo Local Government Area Benue State, Nigeria. *Journal of Research in Forestry, Wildlife and Environment*, 13(4), 137–149.

Anderson, J. R. (1976). A land use and land cover classification system for use with remote sensor data. Washington DC: US Government Printing Office.

Andreas, C. B., Danny, T., Rafael, G., Mauricio, A., Ricardo, B. & Joachim, V. (2017). Assessing the impact of plantation forestry on plant biodiversity: a comparison of sites in Central Chile and Chilean Patagonia. *Global Ecology and Conservation*, 10, 159–172.

Appiah, M., Yeboah, B., Yeboah, M. A. & Danquah, J. A. (2020). Community experiences in the use of modified Taungya system for restoring degraded forests and improving livelihoods in Ghana. *Environmental Management and Sustainable Development*, 9(3), 1–17.

Atser, G., Tahirou, A., Dixon, A., Ekeleme, F., Alloh, J. & Akande, A. (2019). Transforming Oyo State to an agribusiness hub. Ibadan, Nigeria: IITA.

Azeez, I. O., Ikponmwonba, O. S., Popoola, L. & Amusa, T. O. (2010). Activities among forest environments' dwellers in Edo State, Nigeria: implications for livelihood and sustainable forest management. *International Journal of Social Forestry*, 3(2), 164–187.

Azeez, I. O., Popoola, L. & Shulamite, I. O. (2017). An assessment of the forest regeneration potential of the Taungya system of farming in Oyo State, south-western Nigeria. *Southern Forest*, 20, 1–9.

Chamshama, S., Monela, G., Person, A. & Sekiete, K. (1992). Sustainability of the Taungya system at North Kilimanjaro Forest Plantation, Tanzania. *Agroforestry Systems*, 17, 1–11.

Chokkalingam, U. & De Jong, W. (2001). Secondary forest: a working definition and typology. *International Forestry Review*, 3(1), 19–26.

DeFries, R. S., Rudel, T., Uriarte, M. & Hansen, M. (2010). Deforestation driven by urban population growth and agricultural trade in the twenty-first century. *Nature Geoscience*, 3, 178–181.

Edet, D. I., Ijeomah, H. M., Aigbe, H. I. & Ogar, N. E. (2011). Biodiversity conservation in protected areas: the role of indigenous communities in Nigeria. A Paper Presented at the 34th Annual Conference of the Forestry Association of Nigeria (FAN) held in Osogbo, Osun State. 5–10 December 2011.

Eludoyin, O. S., Ugbana, T. & Otali, S. O. (2019). Extent of forest depletion from 1986–2015 as a consequence of land use in Andoni Local Government Areas of Rivers State, Nigeria. *Journal of Applied Science and Environmental Management*, 23(6), 1065–1073.

Enuoh, O. O. & Bisong, F. E. (2015). Colonial forest policies and tropical deforestation: the case of Cross River State, Nigeria. *Open Journal of Forestry, 5,* 66–79.

Fagariba, C., Song, S. & Soule, S. (2018). Livelihood economic activities causing deforestation in northern Ghana: evidence of Sissala West district. *Open Journal of Ecology*, 8, 57–74.

Gibbsa, H. K., Rueschb, A. S., Achardc, F., Claytond, M. K., Holmgrene, P., Ramankuttyf, N. & Foley, J. A. (2010). Tropical forests were the primary sources of new agricultural land in the 1980s and 1990s. *The Proceedings of the National Academy of Sciences (PNAS)*, 107(38), 16732–16737.

Haastrup, N. O., Agboje, I., Lawal, M. O., Fadimu, B. O., Sangotoyinbo, O. A., Mangodo, C., Oripelaye, O. S., Ganiyu, O. A. & Fadoyin, A. S. (2020). Composition of tree species in Onigambari Forest Reserve, Oyo State, Nigeria. *Journal of Applied Sciences and Environmental Management*, 24(10), 1815–1819.

Olajuyigbe, S. (2018). Green gold of Africa: Nigeria's forest, a depleted but resilient renewable resource. *Irish Forestry*, 75, 92–112.

Olayode, O. O. (2019). Spatio-temporal variations of land-cover types in Osho Forest Reserve, southwestern Nigeria. *American Journal of Agriculture and Forestry*, 7(5), 168–176.

Oluwajuwon, T. V., Alo, A. A., Ogana, F. N. & Adekugbe, O. A. (2021). Forest cover dynamics of a lowland rainforest in southwestern Nigeria using GIS and remote sensing technique. *Journal of Geographic Information Systems*, 13, 83–97.

Oyetunji, P. O., Ibitoye, O. S., Akinyemi, G. O., Fadele, O. A. & Oyediji, O. T. (2020). The effects of population growth on deforestation in Nigeria: 1991–2016. *Journal of Applied Science and Environment and Management*, 24(8), 1329–1334.

Phalan, B. & Hajjar, R. (2017). Tropical forest conservation: developing without deforestation. *Nature Plants, 3,* 17120.

Phillips, F. C. & Ceesay, E. K. (2020). Livelihood dependence and forest reserve management in Ijaiye Forest Reserve, Oyo State, Nigeria. *International Journal of Forestry and Horticulture*, 6(2), 26–39.

Sanara, H., Izuru, S., Narumasa, T., Tsugihiro, W. & Shintaro, K. (2014). The impact of agricultural expansion on forest cover in Ratanakiri Province, Cambodia. *Journal of Agricultural Science*, 6(9), 46–59.

Schroeder, J. M., Oke, D. O., Onyekwelu, J. C. & Yirdaw, E. (2010). Secondary forests in West Africa: a challenge and opportunity for management. *International Union of Forestry Research Organizations Secretariat (IUFRO)*, 25, 335–354.

Wineman, A., Jayne, T. S. & Stevens, C. (2021). The relationship between medium-scale farms and deforestation in Sub-Saharan Africa. A United States Agency for International Development (USAID) Paper on the relationship between medium-scale farms and deforestation in Sub-Saharan Africa.

Zeraatpishe, M., Khaledian, Y., Ebrahimi, S., Sheikhpouri, H. & Behtarinejad, B. (2013). The effect of deforestation on soil erosion, sediment and some water quality indicators. Proceedings of the 1st International Conference on Environmental Crisis and its Solution, pp. 602–607.

RESUMEN

El aumento de la población humana, que promueve la conversión de los bosques secundarios en otros tipos de uso del suelo, ha provocado la disminución de las zonas forestales en Nigeria. Este estudio examinó las causas de la pérdida de bosques secundarios en la Reserva Forestal de Osho, Nigeria. Los cambios en el uso del suelo y la cubierta vegetal (LULC) se evaluaron utilizando imágenes Landsat 5 TM y Landsat 8 OLI/TC en cuatro ocasiones durante un período de 38 años (1984, 2013, 2017 y 2022). Los resultados mostraron un aumento de la superficie de plantaciones, terrenos baldíos y tierras de cultivo, lo que llevó a una disminución de la cubierta forestal secundaria. Las tierras de labranza aumentaron de 731 ha a 859 ha a un ritmo de 3,7 ha/año-1, las tierras desnudas aumentaron de 314 ha a 523 ha a 5,5 ha/año-1, las plantaciones aumentaron de 1.105 ha a 1.495 ha a 10,3 ha/año-1, mientras que el bosque secundario se redujo drásticamente de 1.132 ha a 405 ha a 19,1 ha/año-1. A este ritmo de pérdida, el bosque secundario se habrá perdido en la zona de estudio en 2050. La Reserva Forestal de Osho requiere intervenciones inmediatas de gestión impulsadas por leyes y políticas actualizadas, tratamiento silvícola, compromiso comunitario y rehabilitación del ecosistema. Además, la aplicación de una gestión forestal sostenible mejoraría la recuperación del bosque secundario.

RÉSUMÉ

L'augmentation de la population humaine, qui favorise la conversion des forêts secondaires en d'autres types d'utilisation des sols, a entraîné une diminution des zones forestières au Nigeria. Cette étude a examiné les causes de la disparition des forêts secondaires dans la réserve forestière d'Osho, au Nigeria. Les changements dans l'utilisation des terres (LULC) ont été évalués à l'aide des images Landsat 5 TM et Landsat 8 OLI/TC à quatre reprises sur une période de 38 ans (1984, 2013, 2017 et 2022). Les résultats ont montré une augmentation de la superficie des plantations, des terres nues et des terres agricoles, entraînant une diminution de la couverture forestière secondaire. Les terres agricoles sont passées de 731 ha à 859 ha au rythme de 3,7 ha par an, les terres nues de 314 ha à 523 ha au rythme de 5,5 ha par an, les plantations de 1 105 ha à 1 495 ha au rythme de 10,3 ha par an, tandis que la forêt secondaire a considérablement diminué, passant de 1 132 ha à 405 ha au rythme de 19,1 ha par an. À ce rythme, la forêt secondaire aura disparu de la zone d'étude d'ici 2050. La réserve forestière d'Osho nécessite des interventions de gestion immédiates basées sur des lois et des politiques actualisées, des traitements sylvicoles, l'engagement de la communauté et la réhabilitation de l'écosystème. En outre, la mise en œuvre d'une gestion durable des forêts favoriserait la reconstitution de la forêt secondaire.