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RESEARCH

Using Photogrammetry and Deviation Analysis to Conduct Quantitative Monitoring Surveys of WWII Sites in the Pacific

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Abstract

In 2012 a program to investigate the management of underwater cultural heritage (UCH) related to the WWII battle for Saipan was developed with several collaborative partners. The program was conceptualized in response to the creation of the WWII Battle for Saipan Underwater Heritage Trail that launched in 2010 (McKinnon and Carrell in J Maritime Archaeol 10(1):11–27, 2015). With the creation of the trail there became a need to monitor and record both the benefits and impacts of promoting visitation at UCH sites. The monitoring program began on a five-year interval and included archaeological site inspections and the collection of in situ conservation data in 2012 and 2017. In 2017, as photogrammetric survey data was advancing and becoming more useful, it was added to the monitoring program. Again in 2023, site inspections, in situ surveys, and photogrammetric surveys were undertaken providing a total of 15 years of data at five-year intervals. This data has proved invaluable for recording both qualitatively and quantitatively how these WWII submerged sites are changing over time. This article reports on the development of photogrammetric surveys and the use of deviation analysis to demonstrate natural and cultural changes on UCH sites of a WWII battlefield from 2017 to 2023.

Keywords Photogrammetry · Management · Underwater cultural heritage · Pacific · Deviation analysis

Introduction

In 2012 a program to investigate the management of underwater cultural heritage (UCH) related to the WWII battle for Saipan was developed with several collaborative partners. The program was conceptualized in response to the creation of the WWII Battle for Saipan Underwater Heritage Trail that launched in 2010 (McKinnon and Carrell 2011). With the creation of the trail there became a need to monitor and record both the benefits and impacts of promoting visitation at UCH sites. The monitoring program began on a five-year interval and included archaeological site inspections and the collection of in situ

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conservation data in 2012 and 2017. In 2017, as photogrammetric survey data was advancing and becoming more useful, it was added to the monitoring program. Again in 2023, site inspections, in situ surveys, and photogrammetric surveys were undertaken providing a total of 15 years of data at five-year intervals. This data has proved invaluable for recording both qualitatively and quantitatively how these WWII submerged sites are changing over time. This article reports on the development of photogrammetric surveys and the use of deviation analysis to demonstrate natural and cultural changes on UCH sites of a WWII battlefield from 2017 to 2023.

Historical Background

After World War I, Japan received the Northern Marianas, of which Saipan is included, by the terms of the Treaty of Versailles on 28 June 1919, and then later as a mandate under the League of Nations on 17 December 1920. The island was left under the care of the Japanese South Seas Government in 1922 and with that came the Nan'yō Kōhatsu Kabushiki Kaisha (NKKK) operations which primarily focused on developing industry on the island, with special interest in sugarcane manufacturing and fisheries. Instead of employing Indigenous Pacific Islanders, the NKKK encouraged emigration of Japanese and other foreign civilians (Korean and Okinawan) to the island. The sugarcane industry utilized Korean workers, while the commercial fishing industry employed Okinawan civilians. Within years, the emigrated population overtook the Indigenous Pacific Islander population on the island. While many of the Indigenous Pacific Islanders admit to a difficult and complicated relationship with the Japanese military, relationships with civilian emigrants were more favorable prior to and in the lead up to the Pacific War. Japan sought to strengthen its presence in the Pacific in the late 1930s and positive relationships cultivated between the Japanese government and Indigenous civilians began to dissipate (Russell 1984). As tension grew between the Japanese Empire and western powers, the treatment of Indigenous, Okinawan, and Korean civilians began to worsen.

Across the Pacific, word spread that war was coming, however, only Japan knew when and where it would start. Shortly after the 7 December 1941 attack on Pearl Harbor, Japanese military forces initiated air attacks on Guam just south of Saipan in the Mariana Islands. Poorly defended by the U.S., Guam fell to Japanese forces on 10 December within six hours of invasion. With this prize under its belt, the Imperial Japanese Army and Navy (IJN) mounted successful operations across the Pacific in the early years of the war (Rogers 1995; Rottman 2004a).

The U.S. plan to take control of the Marianas from Japanese forces was code-named Operation FORAGER, while the invasion of Saipan was named Operation TEARAWAY . Air raids began in February on Saipan striking Japanese shipping and support installations in February 1944. Marie Soledad Castro, a young Chamorro girl whose father worked at the docks, later related, "That area was all in flames because the Japanese had a lot of storage tanks there," and another witness, Vicky Vaughan, said, "One of my older brothers, Shiuichi, was killed during one of these air raids…We never found his body…like so many, he just disappeared" (Petty 2002, pp. 18, 49). In response, Japanese military forces prepared Operation *A-Go*, which relied upon the support of the IJN and air forces to support troops on the ground in the Marianas.

U.S. forces attempted to gain as much information about the island and Japanese forces by flying reconnaissance missions in April and May. These missions collected aerial photographs of Japanese troop defensive measures and weaponry (Goldberg 2007, p. 23). Additional reconnaissance work included Underwater Demolition Teams (UDT) whose mission was to blast natural obstructions such as the coral reef and record the depth of the lagoon to determine which vessels could be used in the invasion (Kauffman 1986, p. 237).

Operation FORAGER was in full swing by June 1944 when the invasion of Saipan was planned. The invasion was set for 15 June, D-Day. Responsible for this task was the Marine V Amphibious Corps (VAC) consisting of the 2nd and 4th Marine Divisions, the 27th Infantry Division (Army), and the XXIV Corps Artillery (Army). The lower western side of Saipan was chosen as the primary invasion area. Stretching approximately four miles and divided into several zones, this area was most favorable because the size would allow two Marine divisions to land simultaneously. A landing here also allowed the immediate capture of the airstrip at Chalan Kanoa, placing direct pressure on nearby Aslito Airfield. Susupe Point [incorrectly referenced as Puntan Afetña on U.S. military maps (Cabrera 2015, p. 19)] divided the landing beaches. To the north were Red Beaches 1, 2, and 3 and Green Beaches 1 and 2, and to the south were Green Beach 3, Blue Beaches 1 and 2, and Yellow Beaches 1, 2, and 3 (Rottman 2004a).

As favorable as the lower western side of Saipan was for the U.S. invasion, certain limitations remained. The beaches off the lower western side were protected by an extensive coral reef. These had to be negotiated with amphibious vehicles including AMTRACS or Landing Vehicle Tracked (LVT) and Landing Vehicle Tracked Armored (LVT(A)), also known as amphibian tanks. This amounted to approximately 1400 AMTRACS, the largest use to date of amphibious vehicles.

The Japanese defensive strategy used for Saipan and the other Mariana Islands was identical to that of earlier battles at the Gilbert and Marshall Islands: the enemy was to be met and destroyed at the beaches and, if allowed inland, pushed back into the sea by counterattacks (Denfeld 1992). Japanese defenses on Saipan, while substantial, were incomplete by D-Day. The impending U.S. campaign against the Marianas hurried Japanese defensive measures and by the end of February thousands of troops were sent to the Marianas to prepare for battle. By early June some 30,000 troops were on the island (Rottman 2004b). With such an influx of soldiers, Indigenous civilians were forced out of their houses to accommodate the military. Fortunately, many of them had homesteads and farms away from Garapan (the major town), but those who did not were forced to move into caves. Thomasa Camacho Naraja (2018) recalls, "The family compound was taken and occupied by the Japanese soldiers, so my mom and dad moved all thirteen of us children to a cave. We didn't have any water in the cave, and when my dad and sister went to the school nearby to get some, they were threatened by the Japanese."

The Battle of Saipan

On 11 June, Vice Admiral Marc Mitscher ordered all four carrier groups to launch their planes and attack the Marianas, including aircraft from USS *Enterprise*, *Essex*, *Cowpens*, and *Langley*. A total of 208 fighters and eight torpedo-bombers flew that afternoon and were successful in aircraft kills, ship sinking, and the disabling of many terrestrial targets (Farrell 2009, p. 291; Tillman 2005, pp. 55, 62; Okumiya and Horikoshi 1956). Aircraft attacks continued for the next two days (Wheeler 1996, p. 244). Meanwhile, seven U.S. battleships leveled the towns of Chalan Kanoa and Garapan and by 13 and 14 June, more battleships as well as 11 cruisers and 26 destroyers attacked Japanese coastal defenses. "During the first day of action, seven battleships and 11 destroyers fired over 15,000 rounds of 16-inch and five-inch shells at military targets along Saipan's western coast" (Russell 1984, p. 88). The 16-inch shells, 1.5 m long and weighing up to 1225 kg, were the largest ship ammunition the U.S. Navy had at the time (Farrell 2009, p. 303). This had a significant effect on Japanese forces, preventing an air attack on incoming U.S. troops. "The din robbed us totally of all sense of hearing," wrote Maashi Ito, a Japanese soldier (Farrell 2009, p. 293). For those Indigenous civilians who experienced the day the battle began, many did not know what was taking place. Rosa "Chailang" Palacios (2018) recalls, "We were up at our relative's place, the Tudela family, for my uncle's wedding in Dandan. There was so much food on the table…and all of a sudden, my sister said 'Oh my god, it's raining like fire!' Everybody was so scared, they abandoned the food at the table and they all ran away. We had a cave ready with banana leaf just in case there's war and was prepared for maybe twelve people. And they ended up with around thirty."

On 14 June, other crucial preliminary actions took place along the coast of Saipan. Early that morning, UDTs began their mission to demolish reefs and enemy mines, and to mark lanes along the Red, Green, Blue, and Yellow Beaches. This effort was largely successful.

As the sun rose on 15 June, the enormous U.S. amphibious force was assembled for the invasion (Fig. 1). AMTRACS and DUKWs were unloaded, and LSDs (Landing Ship, Dock) launched LCMs (Landing Craft, Mechanized) that held tanks. Battleships, cruisers, and destroyers closed in on the invasion beaches with aircraft screaming overhead toward the shore. With nearly 1500 vessels in all, this great unpacking of soldiers, weaponry, and ammunition was surely an intimidating sight for the Japanese forces and civilians. At exactly 0830 h, AMTRACS carrying hundreds of Marines moved toward the landing beaches as supporting ships and aircraft opened fire. Japanese troops generally held their fire until the AMTRACS reached the coral reef and then they poured artillery, mortar, and machine gun fire on the Marines. Due to the condition of the seas, the Marines had a great deal of difficulty reaching the beach. Numerous AMTRACS were rendered inoperable or destroyed as a result. Dozens of Marines lost their lives when AMTRACS were overturned in the rough surf, but by 0900 nearly 8000 Marines were ashore (Crowl 1960; Rottman 2004a). On this day, the first of the battle for Saipan, some 2000 Marines were killed. Offshore hospital vessels were completely overwhelmed, and wounded men were transferred to other, non-hospital ships for treatment (Crowl 1960; Rottman 2004a).

Over the next two days, the Marines secured and expanded the beachhead. Offshore and in the staging area, a forward-area seadrome facility, referred to both as "Saipan Seadrome" and "Garapan Roads," was expedited. Garapan Roads supported Patrol Squadron (VP) 16 which included Martin PBM Mariners that conducted reconnaissance flights of the surrounding waters of Japan in search of the IJN fleet said to be headed towards Saipan. It was patrol planes of VP-16 that first spotted the Japanese fleet and attempted to radio and report back the news to Task Force 58 (Adamson 2020). The Philippine Sea engagement between 19 and 20 June altered the Pacific War in U.S. favor when Vice Mitscher and his Task Force 58 intercepted the Japanese fleet commanded by Vice Admiral Jisaburo Ozawa in the Battle of the Philippine Sea, also called the "Great Marianas Turkey Shoot" (Crowl 1960; Rottman 2004a).

Through mountainous terrain, tropical conditions, and intense resistance, U.S. forces reached the northern end of Saipan at Marpi Point and on 9 July 1944 at 1615 h. Vice Admiral Richmond Kelly Turner declared Saipan "secure" (Crowl 1960; Rottman 2004a). Shortly after the announcement, suicide jumps began by Japanese civilians who were influenced by their military's propaganda about U.S. soldiers causing harm. Jumps took place at Suicide Cliff, Banzai Cliff, and at other cliffs located along Marpi Point. It is not known how many Japanese civilians perished of their own accord (Cabrera 2015, pp. 23–24).

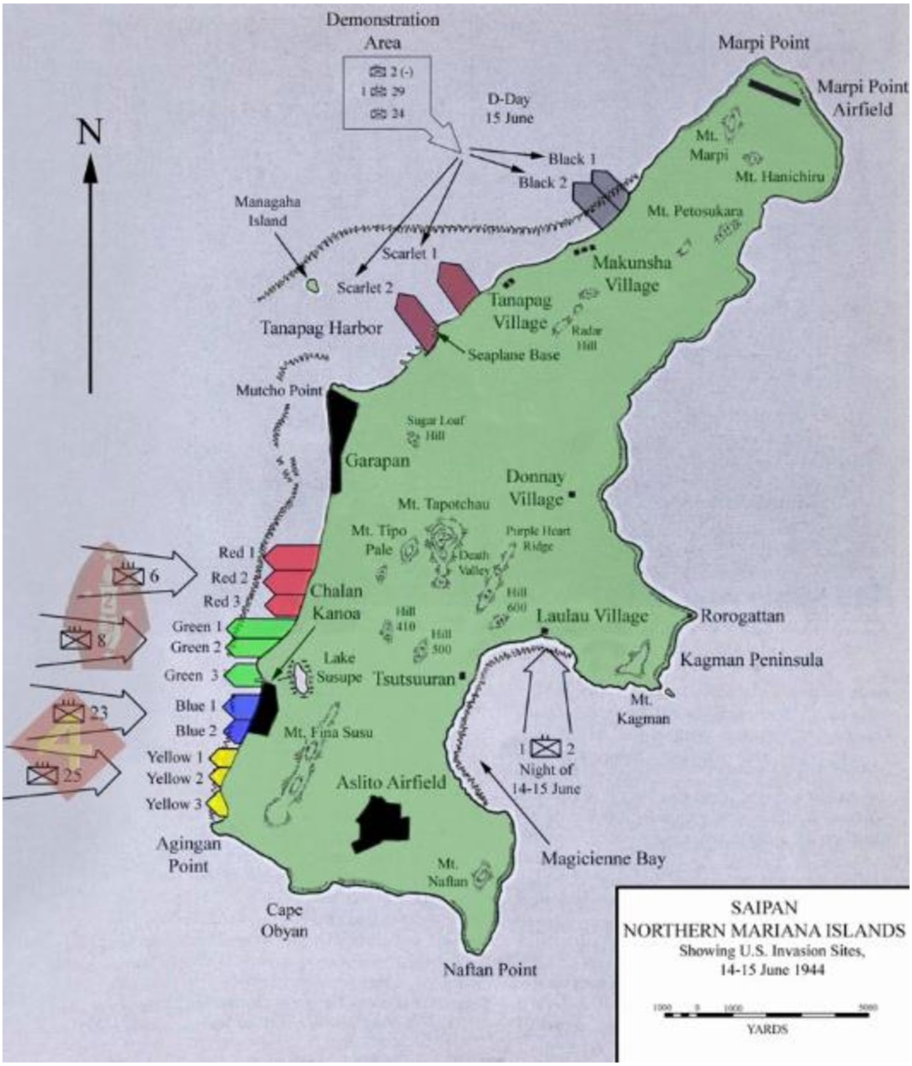

Fig. 1 Invasion beaches of Saipan. Ships of Exploration and Discovery Research, Inc

Mop-up efforts for Japanese troop holdouts continued through July and well into August. The task of removing civilians from caves continued as well but was complicated by the difficulty of discerning whether cave occupants were Japanese soldiers or civilians. Further, there was a language barrier between U.S. troops and island civilians. Once civilians were secured, the U.S. turned their efforts towards cleanup and building a forward operating base for pushing the battle into Japanese homelands. In general, many caves and trenches were filled with the debris accumulated throughout the operations. These Formerly Used Defense Sites (FUDS) have been identified and several studies have documented their impact on the surrounding biota (Denton et al. 2018). Aside from terrestrial dumpsites, large quantities of waste were disposed of at cliff dump sites located at Banzai Cliff and Agingan Point, but there are other areas that have yet to be identified further offshore.

The loss of life during the battle for Saipan was tremendous. Approximately 3426 of the 67,451 U.S. troops who participated in the battle were killed or reported missing in action. Four times this number were confirmed wounded. Japanese losses were far greater; of the approximately 31,629 Japanese troops who participated in the battle, 29,500 were killed or missing (Rottman 2004b).

"Although the Battle for Saipan in WWII's Pacific theater came to a close for the two warring factions, the conflict was far from concluded for the surviving native Chamorro and Carolinian islanders. Regrettably, the ravages of the battle rage on in the memories of the families of the 933 native men, women, and children that died in a conflict not of their making. For these departed, there would never be resolution. They neither died fighting for principles of freedom nor defense of country. They simply died and ostensibly are categorized as collateral damage, but yet even this descriptor was never theirs for the choosing" (Cabrera 2015, p. 24). After the battle, Saipan became part of the U.S. Pacific Trust Territory along with the other islands in the Marianas chain until 1 January 1978 when the new constitution for the Commonwealth of the Northern Mariana Islands (excluding Guam) became partially effective and Saipan became the capital.

Monitoring of WWII UCH in Saipan

As mentioned in the introduction, a monitoring plan for a new heritage trail was developed in coordination with the Commonwealth of the Northern Mariana Islands (CNMI) Historic Preservation Office (HPO) so that trail sites could be assessed for natural and cultural impacts over time (Fig. 2). The concept was to put to the test the adage that heritage trails lead to education which leads to preservation (Scott-Ireton and McKinnon 2015). Questions about whether opening and advertising UCH was going to cause more harm than good were batted around from the inception of the idea of a heritage trail. Thus, it was decided that the monitoring program would follow the development of the trail and a local heritage awareness training for the dive industry. The first monitoring data collection began in 2012, just after the trail was developed, and included archaeological site assessment surveys (mapping and photography) and conservation surveys involving in situ corrosion measurements (pH, Eredox, dissolved oxygen, salinity, temperature, etc.). This was the baseline data needed to begin a long-term management program. Qualitative and quantitative data collected identified all known and potential natural and cultural impacts.

With the development of Agisoft software in 2010 which allowed for the creation of digital 3-D models, photogrammetry was implemented in both terrestrial and underwater contexts to record cultural heritage sites. Since that time there has been an expansion of the use of this technology beyond comparison to any other methodology or technology that has been introduced previously, including side scan sonar and magnetometry. This explosion is largely because photogrammetry is accessible, expeditious, and easy to use. For example, what once took three to five days with a team of four to six divers to record a site, now takes a single diver 30 minutes to record *and* site models are more accurate. Given that anyone can learn the methodology for collecting the photographs needed for a photogrammetric model and that accessible, off-the-shelf cameras such as a GoPro can be used, the range of actors can be extended from trained maritime archaeologists to other similar practitioners like marine biologists and even citizen science divers making it an incredible tool for maritime archaeology.

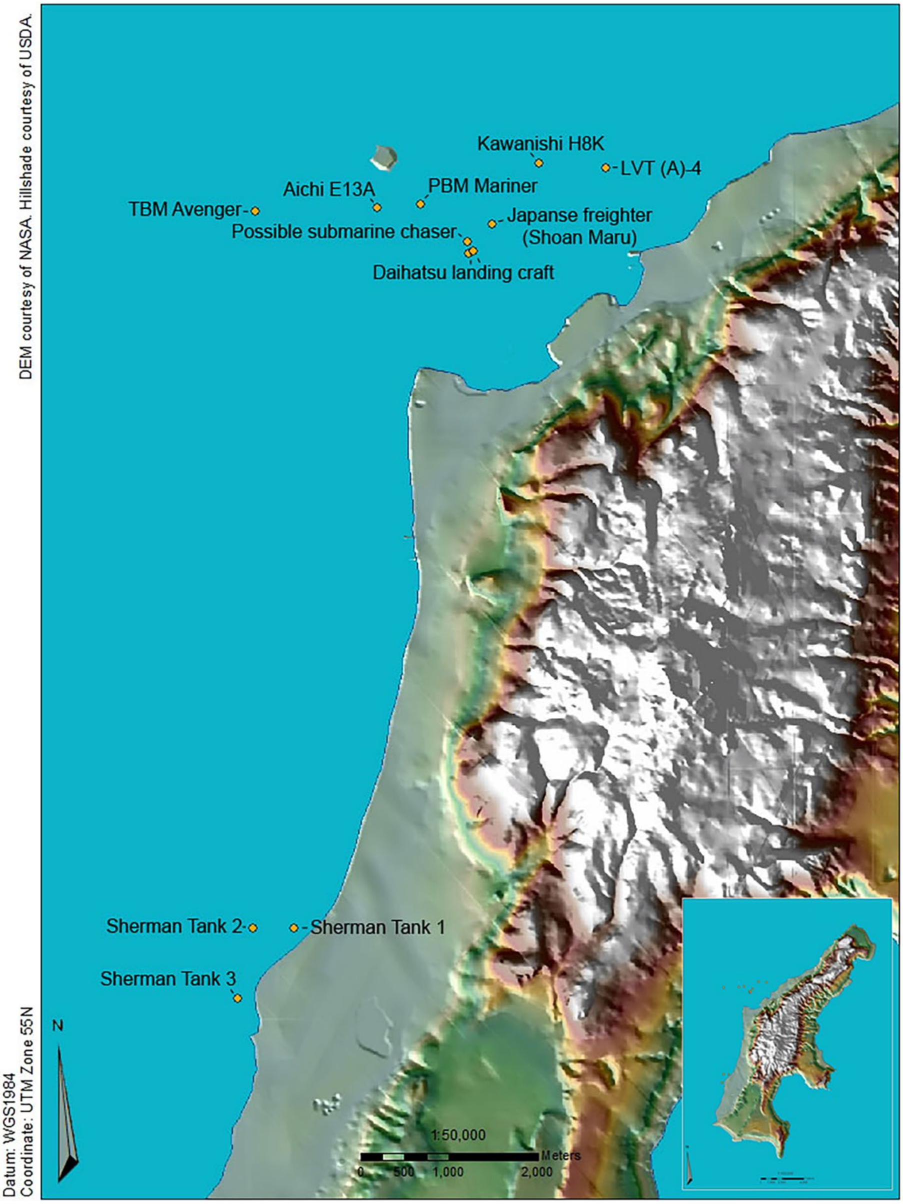

Fig. 2 Sites on maritime heritage trail

Since its implementation, archaeologists have used several terms to describe the methodology of using 3D photogrammetry, including: Structure from Motion (SfM), Multi-Image Photogrammetry, Computer Vision Photogrammetry, and Close Range Photogrammetry. There have also been a number of academic publications produced about the method and use of photogrammetry to record underwater cultural heritage sites since its implementation and expansion. One area, however, that has not been explored fully is the potential for using photogrammetry as an efficient and accurate method for monitoring of UCH sites. The remainder of this paper attempts to contribute to this area of growth in monitoring.

After 2012, and during the period Yamafune was developing a photogrammetry method for underwater sites, a plan was hatched to include photogrammetry in the next five-year monitoring interval at the WWII Battle for Saipan Underwater Heritage Trail so that additional quantitative data could be collected, and models could be used for outreach and education. Thus in 2017, the team returned to collect additional archaeological, conservation, and photogrammetric data. A total of eight sites including shipwrecks, assault vehicles, and aircraft were recorded using photogrammetric surveys. Three Sherman tanks included in the heritage trail were unable to be modelled due to their being located partially submerged and a Japanese freighter *Shoan Maru* was not modelled as it is a very large site and would take multiple days to survey. Photogrammetry proved useful in comparison to the previous still and video photography as it demonstrated both minimal and significant natural and cultural changes on sites. It also demonstrated that the hand-drawn, diver-based site plans were less accurate, and that photogrammetry was truly an asset for quick and accurate recording and critical to any monitoring program. An attempt was made to use legacy still and video photography from 2012 to recreate 3D models, however it was unsuccessful. There is hope that another attempt may be fruitful as the software has advanced significantly in the last five years.

In 2023, the monitoring team returned to Saipan for a 15th year of archaeological and conservation surveys and ten years of photogrammetric data. A total of 13 sites were photogrammetrically modeled including the Sherman tanks which were unable to be modeled using previous technology. Yamafune conducted photogrammetry training with local Japanese recreational divers and attempts to model *Shoan Maru* were undertaken, but not yet completed. Additionally, deeper sites were modelled utilizing an ROV system. The results of the photogrammetric data for all sites that had 2017 and 2023 data were processed using deviation analysis software CloudCompare. This process was accomplished by importing two point clouds and running the Cloud to Cloud Distance tool. This provides a sort of "heat map" indicating differences between the two point clouds. The Cloud to Cloud distances can be expressed in distance to the nearest point in compared clouds and reference clouds to create a contour scale of differences. Below are the results of the analysis of sites.

Japanese Auxiliary Submarine Chaser

A possible Japanese Auxiliary Submarine Chaser lies on its starboard side in approximately 9.1 m (30 ft) of water on a sandy bottom in Tanapag Lagoon. The site is discrete and comprised of a tightly clustered section of bow, disarticulated midships hull, and minor structural elements; however, the entire stern is missing (Fig. 3).

Historical research revealed that two auxiliary submarine chasers, *Kyo Maru 8* and *Kyo Maru 10*, were reportedly sunk during U.S. air raids in February 1944 (Jentschura et al. 1977, p. 225). *Kyo Maru 8* and *Kyo Maru 10* were built in 1938 as part of the Supplementary Fleet Programs that began in 1931 under agreements with merchant shipbuilders. Both were designed to be used as whaling ships after the war. Shortly after completion, they were requisitioned as auxiliary submarine chasers (Jentschura et al. 1977, p. 225). These vessels were used in the Pacific to patrol for U.S. submarines and to escort convoys of Japanese warships. Their sleek hull design was suitable for high-speed chases, whether it was for whales or submarines. *Kyo Maru 8* and *Kyo Maru 10* were steamers of 341 tons

Fig. 3 Possible Japanese auxiliary submarine chaser. Photo by Hiroyuki Tomura, 2023

(Jentschura et al. 1977, p. 225), which suggests the use of single or double expansion vertical steam engines and water tube boilers. Other similar ships of the same approximate tonnage range in size from 48.7 to 64 m (160–210 ft) in length. These ships typically had their bridge and machinery amidships with spaces forward and aft for armament and depth charge launchers.

The subchaser site lies on its starboard side and is approximately 60 m (200 ft) long by 15 m (50 ft) maximum width (Fig. 4). Maximum exposure height of the main structure is approximately 3 m. There is little scattered debris away from the main concentration of the site. Approximately 12 m (40 ft) of the sharp bow section remains intact. It is possible

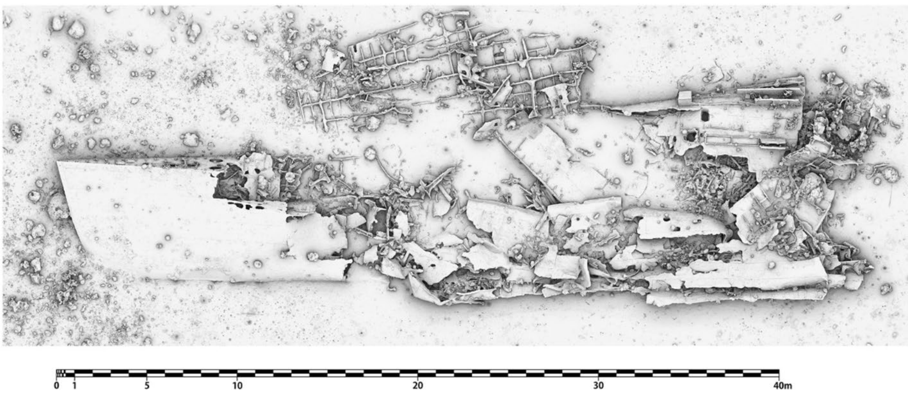

Fig. 4 Subchaser site plan from photogrammetric model, 2023

that the upper deck of the bow has been cut away from the vessel. Small hatch holes are present just aft of the stem leading into the narrow cargo spaces forward. The beam of the aft end of the remaining bow section is 3.9–4.8 m (13–16 ft) wide. The remainder of the ship is badly broken up, although the wreckage generally follows the original line of the ship. No evidence of the engine or boilers is present, however, there is what appears to be a section of a funnel in the midship section. There is no evidence of the stern, steering gear, or propellers.

The disarticulated nature and missing features make it difficult to understand what happened to the site, however this could be the result of post-war cleanup, salvage, explosives training operations, or combinations of all. The subchaser was reportedly impacted during immediate post-battle cleanup and during the 1950s by post-war clearing and salvage as navigation hazards. According to NOAA navigation chart 81,076, the ship lies in an area that was cleared to a depth of 3.04 m (10 ft). The extensive destruction to the site suggests it may also have been used in the 1950s for demolition training by the Central Intelligence Agency (CIA) as part of the Naval Technical Training Unit (NTTU). As such, the site remains unidentified as to vessel name.

In 1984, munitions were visibly scattered in the wreckage. These were reported as “4 inches in diameter and 15.6 inches long” (101 mm by 396 mm long) (Pacific Basin Environmental Consultants (PBEC) 1984, pp. 10–11). In 2010 and 2012 three munitions were visible on site but in 2017 there were only two visible (McKinnon and Carrell 2018, p. 42). It appears that the wreck is not subjected to regular burial/exposure cycles. Limited sediment coverage has occurred on some hull structure lying on the seabed but due to the relatively high profile of the shipwreck remains, this negates extensive burial. The establishment of hard corals indicates that significant accumulation of sediment does not readily occur.

A comparison of photogrammetric models from 2017 and 2023 show areas of significant changes on the site, particularly in the bow (Fig. 5). A large section of the bow deck and hull have collapsed on the site with changes measuring 25.1 cm (Fig. 6). Two other sections of hull on the starboard and port side show changes. Possible explanations for changes in these areas could be damage from anchoring on site to send down divers.

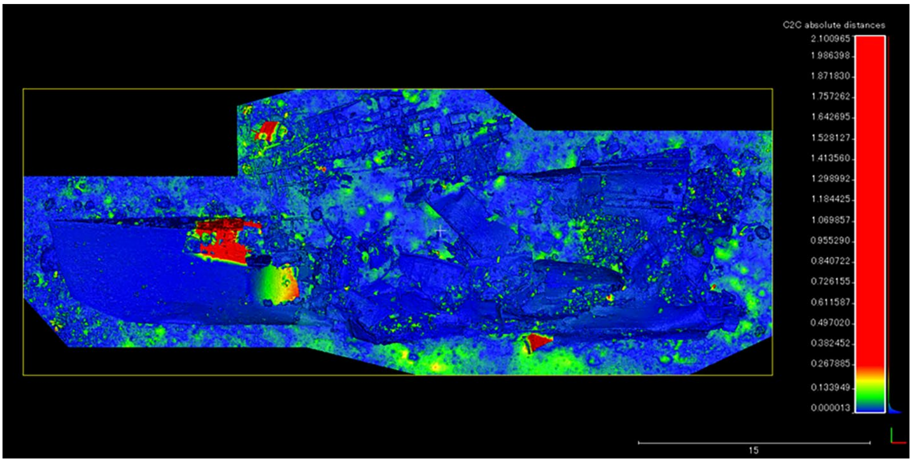

Fig. 5 Deviation analysis of subchaser from 2017 to 2023

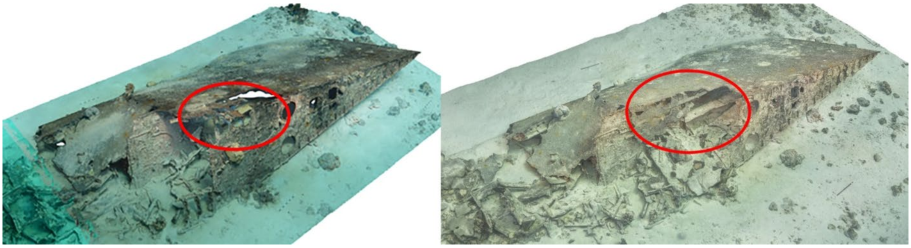

Fig. 6 Bow collapse shown in red circle (2107 left; 2023 right)

However, the bow damage is likely due to structural collapse from deterioration and should be monitored for further deterioration. Presently the team is comparing photogrammetric data to corrosion data to better understand changes to the site.

Japanese Daihatsu Landing Craft

Two Japaese Daihatsu landing craft are located approximate 45 m (150 ft) apart on a sandy substrate in approximately 11 m (35 ft) of water in Tanapag Lagoon (Fig. 7). Daihatsu Landing Craft 1 is largely intact while Daihatsu Landing Craft 2 is less so.

During WWII the IJN operated hundreds of landing craft in support and defense of their island holdings. Designed as amphibious transport vehicles they were utilized during WWII and the battle for Saipan to move equipment and troops and defend the island during U.S. invasion. Eighty-five percent of all Japanese landing craft were of the Daihatsu type and could mount two light machine guns or two to three 25-mm/60 AA guns (Merriam 1988). The craft were designed with powerful 80 horsepower diesel/kerosene engines, relatively flat bottoms and rear weighted, which allowed the craft to back off the beach. The propeller drive was mounted in a tunnel hull protecting it from shallow water hazards (Miller 2018). On 18 June 1944 as U.S. forces were still pushing through the southern and middle areas of the island, the Japanese military loaded 35 barges, or landing craft, and attempted a counterattack via the water. In route, the destroyer USS *Phelps*, with a contingent of landing craft gunboats (LCI-G) and amphibious tractors (LVT-A) intercepted the Japanese attack, destroying many and deterring all with 13 vessels reported sunk (Clancey and Jewell 2019). It is likely these two and a third landing craft not on the trail are part of that counterattack.

Craft 1 has been identified as a Daihatsu 14 m Japanese Landing Craft (McKinnon and Carrell 2011, p. 93) (Fig. 8). It is constructed primarily of welded steel and the dimensions are 14.58 m (48 ft) in length, 3.35 m (11 ft) in width, with a 0.76 m (2.5 ft) draught (Budge 2017). The vessel is upright and largely intact although the port midship hull section has collapsed. The maximum height of the main structure rises approximately 2–3 m (6–9 ft) above the seabed. A deck winch with wire remains in position on the upper stern deck level. The steering wheel has been displaced and is lying on the upper stern deck. The captain's armor shield lies on the seabed on the port side of the stern. The vessel is partially buried in the stern, but the upper half of the rudder is visible. Limited burial has occurred with sand accumulation in the cargo bay. The engines are in situ and can be seen through an open hatch in the stern; the propellers are also visible under the stern, suggesting that they are still connected to the engine via the propeller shafts.

Fig. 7 Japanese Daihatsu Landing Craft 1 (top); Craft 2 (bottom). Photograph by Hiroyuki Tomura

Craft 2 is located about 45 m (150 ft) southwest of Daihatsu 1 and is also a Daihatsu 14 m Japanese Landing Craft (McKinnon and Carrell 2011, p. 98). The vessel is upright on the seabed and is disarticulated. The maximum height of the main structure rises approximately 2–3 m (6–9 ft) above the seabed. Large sections lie separate and astern of the wreck and structural remains have collapsed on the port side of the vessel. The engine is missing and presumed salvaged, but the rudder and propeller shaft remain in situ. Limited burial

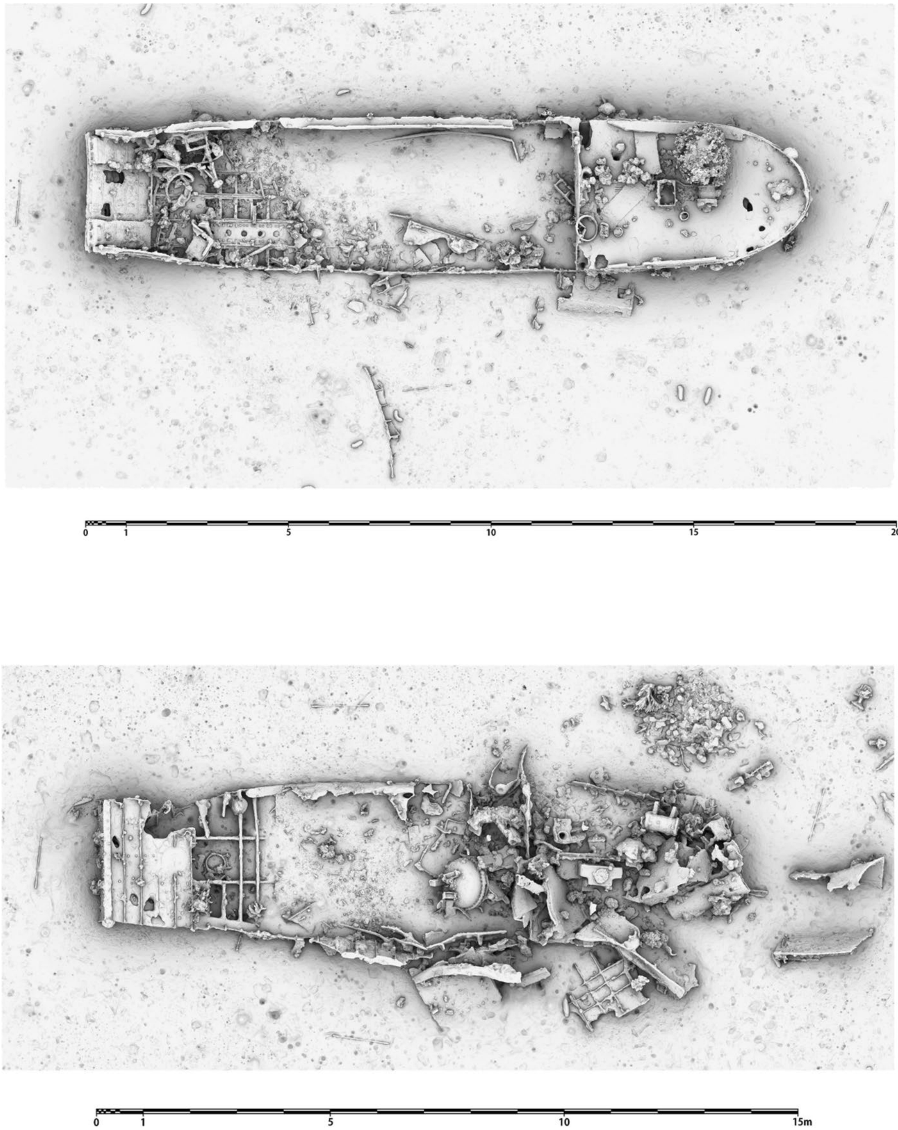

Fig. 8 Site plans from model for Craft 1 (top) and Craft 2 (bottom), 2023

has occurred with sand accumulation in the loading zone and around the lower profile areas.

There are areas of active corrosion evident on both landing craft, indicated by the presence of the typical red/brown “rust” spots on the surface of the vehicles. In 2017 it appeared that the craft were not subjected to regular burial/exposure cycles. Sediment had partly covered the lower profile areas and the establishment of some hard corals indicated that significant movement of sediment does not readily occur. However, reviewing the model comparisons between 2017 and 2023 tells a different story. A considerable amount of sand movement, in some places 50 cm, has occurred around both between 2017 and 2023. For example, Daihatsu 1 has had 20 cm of accumulation and scouring with 2.11 m of sand shift total on site.

While the craft lie in the protected lagoon area, they have the potential to be affected by storm conditions. A 2012 survey of Daihatsu Landing Craft 2 showed little change from a 2010 survey; however, significant changes were noted during a 2017 survey. The stern deck had collapsed and structure previously buried was exposed, while other structural areas that were exposed became partially buried. The port hull deteriorated more, and many areas of hull were almost completely graphitized. In 2015 a super typhoon category 5 storm named Soudelor hit the island and may be the cause for the above-described changes. While circumstantial because the site was not visited immediately before and after super typhoon Soudelor, the evidence suggests the changes and event are likely connected.

A review of the 2017 and 2023 deviation analysis shows other significant changes in discrete areas (Fig. 9). Perhaps the most shocking change is the wheel on Daihatsu 1. The wheel has been picked up and moved, likely by divers wishing to take photographs. This activity has caused three spokes to deteriorate. Soon the wheel will no longer look like a wheel and will be unrecognizable and uneventful for divers. While surveying the site in 2023, between two survey dives, a tourist dive boat put divers down on the site and the wheel which was on the deck during the first survey dive was found in the hull on the second dive, indicating divers picked it up and moved or dropped it (Fig. 10). Other changes to the site include gunwale and hull collapse, perhaps related to anchoring due to their discreteness, and interestingly, changes in corals in the bow and stern (Fig. 11). These biological changes were of interest to the marine biologist on the team.

Unfortunately, significant changes to Daihatsu 2 have also been noted with collapse in both the bow ramp and stern deck and hull (Fig. 12). These are large changes and are not likely related to cultural impacts such as visitation. A third Daihatsu located in 2012 that is not on the heritage trail was modelled and compared between 2017 and 2023 and there are also significant changes in the bow and stern with collapse of structure, as well as large sediment shifts. These changes to a site that is not on the heritage trail and actively promoted for visitation suggests that natural transforms are the most significant factors for

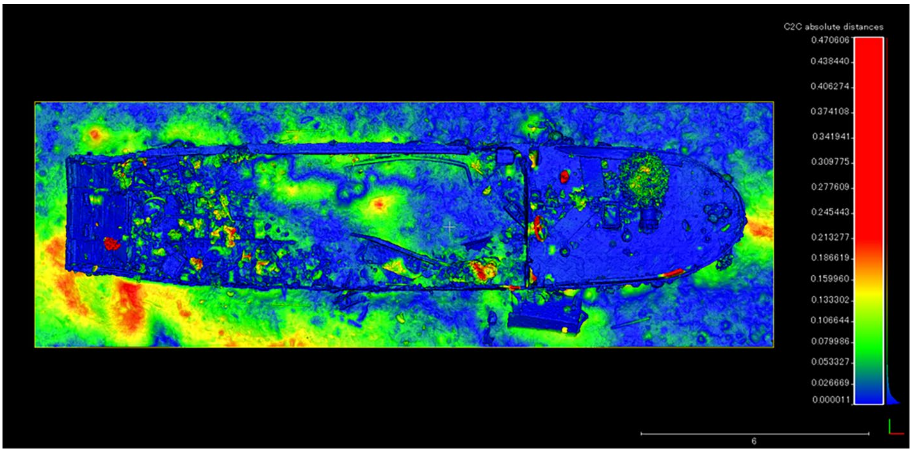

Fig. 9 Deviation analysis of Craft 1

Fig. 10 Steering wheel in 2017 (left) and 2023 (right). Note new box of bottles stacked near wheel in 2023 photograph

change on these sites and cultural transforms cannot account for all changes. Questions about whether these smaller sites need some form of intervention or assistance in preservation remain open for discussion. Corrosion data can provide useful information about the existence of residual metal and if sacrificial anodes might be effective in supporting preservation.

U.S. Landing Vehicle Tracked (A)-4 (LVT(A)-4)

A Landing Vehicle Tracked (Armored)-4 or LVT(A)-4 lies largely intact on a sandy seafloor near the fringing reef in 3 m (10 ft) of water in Tanapag Lagoon (Fig. 13).

The amphibious tractor was first conceived by Donald Roebling in 1935, who developed the life-saving vehicle "Alligator" to rescue hurricane victims. The original design called for a 24-foot long aluminum craft on tracks powered by a 92-horsepower engine. Mounted to the tracks were bolt-on cleats (grousers) which acted as paddles in water and provided traction on land. It had a top speed of 25 miles per hour on land and two miles per hour in the water. After several rounds of experimentation, *Life* magazine featured the third prototype in 1937, which caught the U.S. Army's attention. With some persuading, the Army convinced Roebling to produce the vehicle for military use (Mesko 1993).

The LVT-1 was the first production model and sported an all-steel construction, slanted driver's cable, flotation sponsons, and a rigid suspension system for the tracks (Bailey 1976, pp. 41–43). A total of 1225 were distributed to the U.S. Marines and Army and Allied Powers. Army planners initially intended the LVT-1 to serve as a cargo carrier (Bailey 1976, p. 53). During the Solomon Islands campaign, troops discovered design issues in the track and suspension system along with speed deficits which prompted a redesign (Mesko 1993, pp. 7–9).

The new LVT-2 design included changes to tracks, pontoons, and grouser design, a new engine, changes in hull structure, and more firepower (Mesko 1993, p. 9; Metz

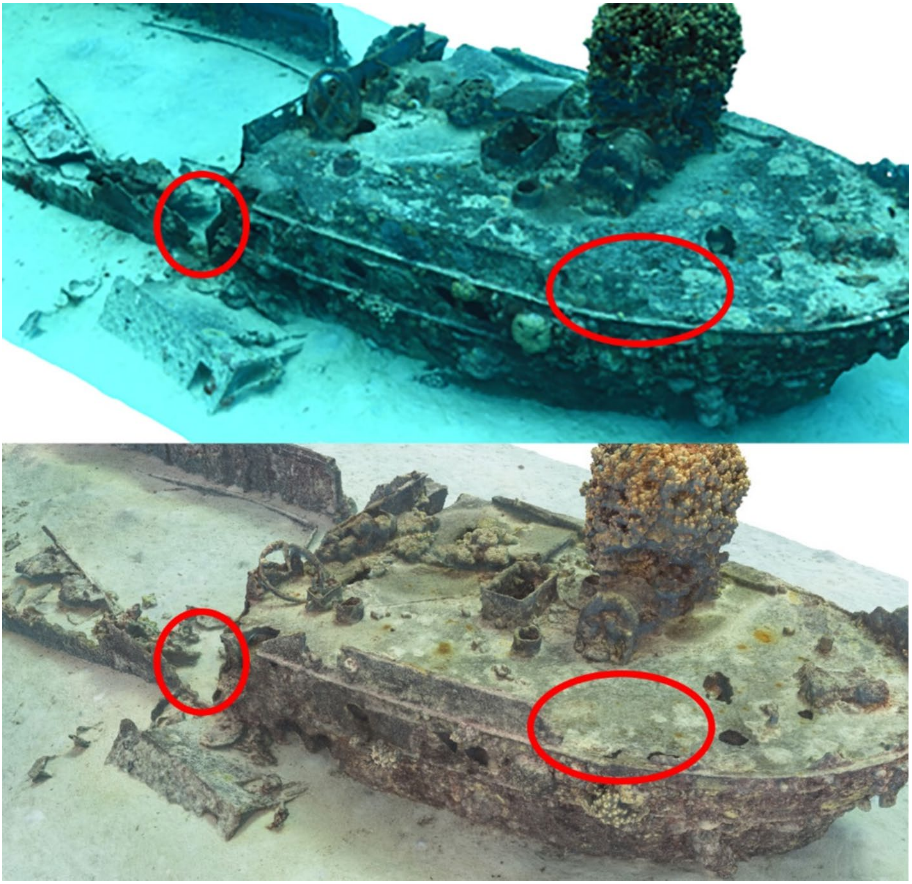

Fig. 11 Gunwale and hull deterioration circled in 2017 (top) and 2023 (bottom)

1986, p. 4). Food Machinery Corporation produced 2962 LVT-2s between 1943 and 1944 (Mesko 1993, p. 9). The LVT-2 also came in a more heavily armored version carrying the designation LVT(A)-2 and a total of 450 LVT(A)-2 were produced (Mesko 1993, pp. 9–13). Both the LVT-2 and LVT(A)-2 saw their first combat at the Battle of Tarawa as U.S. forces conducted their offensive drive through the Central Pacific (Croizat 1953, pp. 88–89). The commander of the Marine landing force, General Holland Smith, said that without the LVT, the landings would not proceed (Smith and Finch 1989, p. 20). Thus, the LVT-2s were utilized as assault transports for the first time. This heralded a radical change in amphibious assault activities and general military planning and doctrine for the Pacific campaign and beyond (Arnold 2010, pp. 3–16). Prior to the assault, troops added boiler plate to the front of 50 of their LVT-2 cabs and mounted an additional 0.50 caliber and two 0.30 caliber machine gun mounts to their vehicles (Bailey 1976, pp. 84–91). At the same time, 75 LVT-1s coming from New Zealand had two additional 0.50 caliber guns and one 0.30 caliber gun added, along with 0.25-inch armor plating on the front and sides of the cab and two grappling hooks at the stern (Bailey 1976, p. 84).

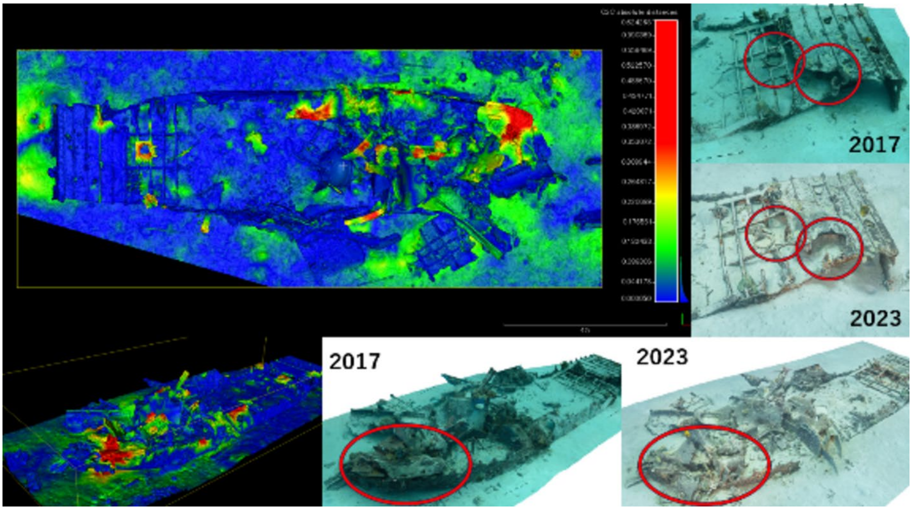

Fig. 12 Craft 2 comparison from 2017 to 2023

Fig. 13 LVT (A)-4. Photo by Hiroyuki Tomura

After the Battle of Tarawa, the first artillery-based amphibious tractor (nicknamed Amtanks) was designed and built (Mesko 1993, p. 21). Designated LVT(A)-1, a total of 510 LVT(A)-1s were produced in 1944 (Mesko 1993, pp. 21–24). The class saw its first combat during the assault on the Marshall Islands, starting with the Kwajalein Atoll. After the assault, the LVTs carried out logistical duties (Bailey 1976, p. 106).

After the assault on the Marshall Islands, the next critical battle for U.S. forces was Saipan in the Marianas Islands (Arnold 2010, pp. 3–20). The LVT-4 served as the assault force's new cargo and troop carrier for the Mariana Islands (Metz 1986, p. 5). From the bow to the driver's cab, the LVT-4 closely resembled the LVT-2. Engineers relocated the engine to the rear of the cab to free up cargo space and added a rear ramp to allow troops a safe way to disembark the vehicle. A total of 8351 were produced, along with armor kits, but they did not receive an armored designation (Mesko 1993, p. 14).

At the same time, Food Machinery Corporation also created a new artillery LVT, the LVT(A)-4. The new vehicle sported a longer body to carry a larger 75-mm howitzer in the turret (Mesko 1993, p. 27). The larger turret was deliberately picked due to its ability to penetrate heavy fortifications like pillboxes and bunkers thanks to its high trajectory and high explosive shell. The turret was only partially enclosed, however, which exposed crew to enemy grenades and mortars. Early designs showcased a rear 0.50 caliber machine gun, which was left completely exposed because of the turret design (Bailey 1976, pp. 163–12). It was later replaced with two pintel-mounted 0.30 caliber guns and a ball-mounted 0.30 caliber gun at the radio operator's seat. These, along with field expedient armor modifications would later produce an LVT(A)-4 design nicknamed unofficially the "Marianas Model" (Mesko 1993, p. 30). A total of 1890 vehicles were produced (McKinnon and Carrell 2011, p. 115). As soon as troops received their LVT(A)-4s they modified them in preparation for Saipan. Popular alterations included adding an armor shield around the 0.50 caliber gun, adding a front mounted coaxial 0.30 caliber gun, armor plating to the bow, and sandbags around the top of the vehicle (Bailey 1976, pp. 163–168).

The LVT(A)-4 lies intact in approximately 3 m (10 ft) of water with a length of 26 ft 1 in, and a beam of 10 ft 8 in (McKinnon and Carrell 2011) (Fig. 14). It has been identified as an early production LVT(A)-4 based on the presence of a semi-enclosed 75-mm howitzer turret with a single rear-facing 0.50 caliber machine gun mounting in the rear,

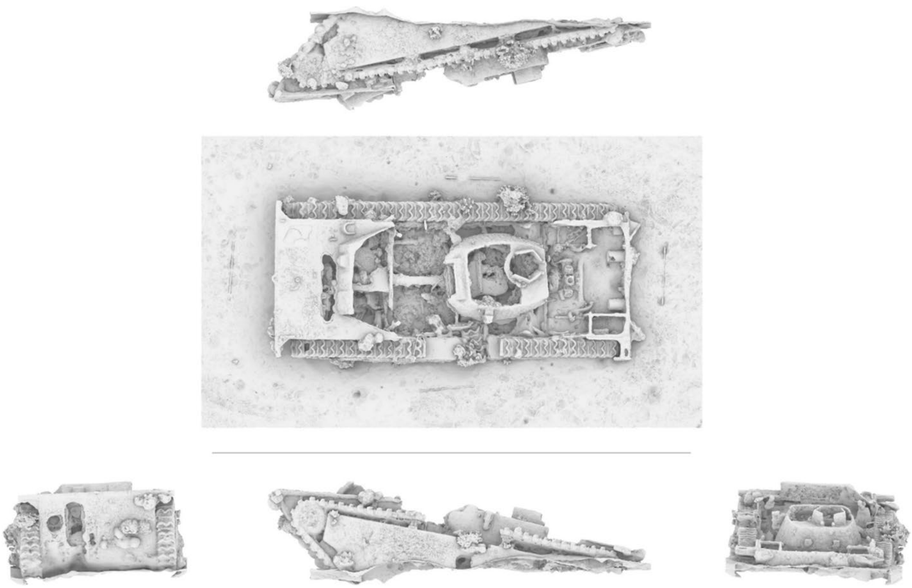

Fig. 14 Site plan of LVT(A)-4 from photogrammetric model, 2023

a horizontal tow ring, and a single armored viewport (Arnold 2010, pp. 5–2). Key features on the vehicle are related to field expedient armor modifications, which are modifications undertaken by the vehicle's crew to increase the craft's survivability, durability, and combat effectiveness. The modifications include: a coaxial mounted 0.30 caliber machine gun port, a feature not standard on base models; a semi-enclosed octagonal shield made of 3/8th inch steel protecting the 0.50 caliber machine gun on the rear of the turret; and addition of boiler plate to strengthen the bow (Arnold 2010).

Archaeological investigations revealed salvage patterns closely mirror instructions for disposal found in the Army's technical manual for the LVT(A)-4 and include: compromises in the superstructure's support framing; removed armor plating across the deck, cabin, and engine room; a hole directly in front of the driver's cabin (which may have been made with a cutting torch); stripped interior (except for steering controls and instrument panels); two large holes in the pontoons on both sides of the vehicle; missing hoses, pumps, filters, vents, generators, air cleaners, and oil coolers; removed engine cylinder heads and valve covers; and a cut in the rear bracket where splashguards are missing (Arnold 2010).

Overall, the LVT(A)-4 is believed to have undergone pre-disposal salvage and disablement before being driven under its own power to its present location and sunk. Had the damage occurred during battle at the site, it is likely there would be a debris scatter and obvious damage to the vehicle (Arnold 2010, pp. 6–13). It is possible this LVT(A)-4 was damaged beyond repair on land and stripped in accordance with the Army's manual. The only discrepancy with the manual is that the vehicle rests in shallow water rather than at the 50-ft depth the Army called for (Arnold 2010, pp. 6–13).

The Tanapag LVT(A)-4 is in a low energy hydrodynamic environment protected by the fringing coral reef and out of the main ship channel (McKinnon and Carrell 2011, p. 122). A comparison of the 2012 and 2017 surveys revealed some changes to the site (Fig. 15). One noted change was a small piece of track that broke off in the midship section on the port side. Additionally, the turret settled further into the deck. Deviation analysis of 2017 and 2023 data indicates that sediment has accumulated in the stern area of the vehicle,

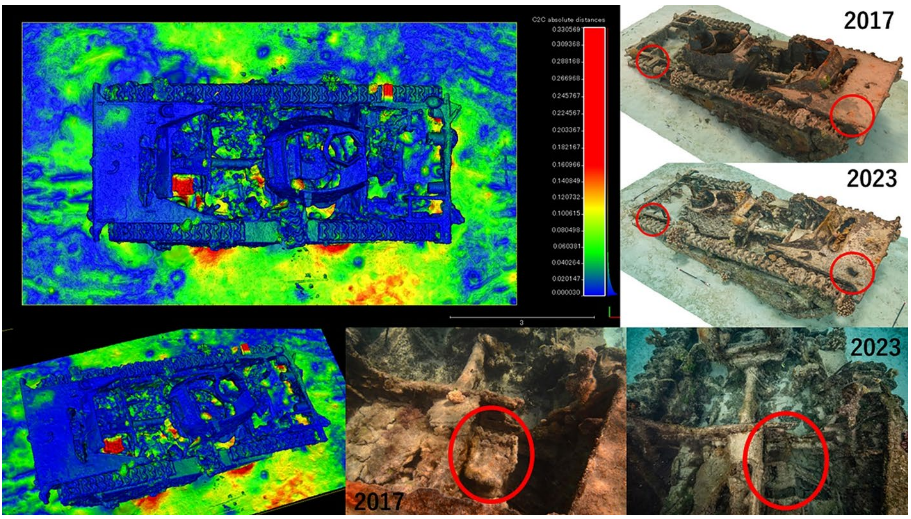

Fig. 15 Comparison between 2017 and 2023 on LVT(A)-4

another section of track has deteriorated, and a small area on the bow that showed active corrosion has now become a larger hole in the hull plating. Similar to the Daihatsu landing craft, the LVT(A)-4 should be monitored and considered a candidate for sacrificial anodes.

Japanese Aichi E13A

The Japanese Aichi E13A, Allied code name "Jake" (Baker 1992, p. 13) and locally known as the "Zero", is largely intact and lies inverted in approximately 8 m (23 ft) of water on a sandy seabed in Tanapag Lagoon (Fig. 16).

Before the start of World War II, the IJN needed long-range floatplanes that could act as escorts to maritime convoys and fly reconnaissance missions (Caoimh 2004, p. 154; Bell 2010, p. 38). In September 1937, the IJN commissioned three companies, Aichi Kokuki, Nakajima, and Kawanashi, to design and build a three-seat reconnaissance floatplane that was able to travel long distances at high speeds (Francillon 1970, p. 277; Bell 2010, p. 38).

Kishiro Matsuo led the Aichi Kokuki design team in creating the first prototype of the Aichi E13A1, which was modeled after the two-seater aircraft E12A1 (Francillon 1970, p. 277; Bell 2010, p. 38). In 1938, the first prototype of the Aichi E13A was created. It had a 1060 horsepower Mitsubishi Kinsei 43, 14-cylinder, air-cooled radial engine (Francillon 1970, p. 277; Bell 2010, p. 38). In 1940, the IJN accepted the design and prototype, and designated the aircraft as "Navy Type 0 Reconnaissance Seaplane," which was numerically the most important Japanese Seaplane at the time (Francillon 1970, p. 277; Bell 2010, p. 38). In 1941, the aircraft made its combat debut.

As a long-range reconnaissance floatplane, the Aichi E13A was used by the IJN in many significant operations before and during World War II. It was armed with one flexible rear-firing 7.7-mm type 92 machine gun and was able to carry one 250-kg bomb, or four 60-kg

Fig. 16 Aichi E13A. Photograph by Hiroyuki Tomura, 2023

bombs or depth charges. The aircraft was used for attacks on the Canton-Hankow railway in China (Caoimh 2004, p. 154; Bell 2010, p. 39). In addition, it was used for reconnaissance surveys in Europe, as well as in the Pacific before the IJN's attack on Pearl Harbor (Caoimh 2004, p. 154; Bell 2010, p. 39; Gamble 2013, p. 241). Because of its efficiency and effectiveness, the IJN kept the aircraft on ships and shore bases where they were active (Francillon 1970, p. 278; Bell 2010, p. 39). The limitations of the aircraft included having a small fuel tank, minimal crew protection, and limited defense armament. Due to these limitations, the Aichi E13A was used for bombing missions where air opposition was minimal during the war (Bell 2010, p. 39).

The aircraft is lying at a depth of about 8 m (25 ft) with the maximum exposure height of the main structure at about 1.5 m (5 ft) above the seabed (Fig. 17). The aircraft is largely intact with both pontoon floats disarticulated but adjacent to the aircraft. It is inverted and listing to starboard at an angle of approximately 30 degrees with the starboard wing imbedded in the sand while the port wing is suspended above the seabed unsupported. The tail section is buried in the sand. The bomb-dropping mechanism is seen in the center of

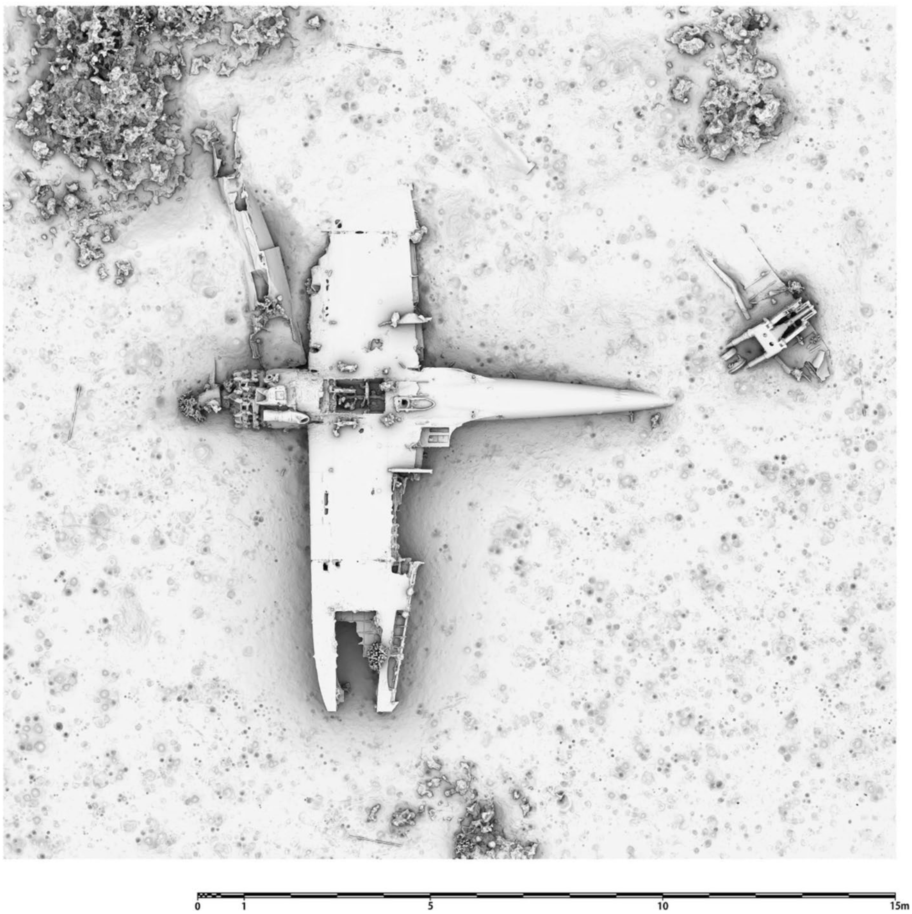

Fig. 17 Site plan from model for Aichi E13A, 2023

the aircraft wings, and aft of the mechanism, there is a reconnaissance camera sight hole. Both pontoon floats are detached and lying next to the aircraft. There are bullet holes and a crimped area in the tail section that suggest that the plane may have been intentionally disposed of during or after the battle or an attempted salvage or recovery was conducted after it was damaged (McKinnon and Carrell 2011, p. 57; McKinnon and Carrell 2014, p. 33). A large piece of unassociated landing gear from another type of aircraft is located just north of the tail. This gear was deposited during the 1990s during a port upgrade project (CNMI HPO 1993).

A thin mucilaginous layer is present on the aluminum surface of the wreck and small areas of disintegration on the wings are noticeable. Hard coral growth appears on the aircraft with the largest on the nose cone of the propeller. There is also algae growth on the under-surfaces of the site, which is denser than the growth on the upper surfaces with a greater variety of colonizing species underneath.

Seasonal currents shift sand on site and between 2010 when it was first recorded and 2012 and 2017 enough sand shifted off the site to expose both pontoons that were previously buried (McKinnon and Carrell 2011, p. 55). Analysis of the 2017 and 2023 models indicate significant shifts in sand with a 13.5 cm decrease in sand in the tail area, an 18 cm decrease on the port, and a 30 cm decrease forward near the engine with a total of 19 m^2 of sand shift within a 211 m^2 area (Fig. 18). Additionally, some deterioration of the port rear wing is evident and an aileron frame which is a hinged moveable part, has likely been moved by a visiting diver. Most concerning is that the starboard wing which hangs free, unsupported by the seabed, is beginning to sag (measured at 3.5 cm) and may eventually collapse. This change would significantly alter the aesthetics of this site and warrants some management attention. Perhaps a reinforcement brace would assist in keeping the wing from collapsing and allow future divers the rare experience of swimming under an aircraft wing.

The site is a significant and regularly visited snorkel and dive spot as well as a glass-bottom boat stop. Dive instructors indicate that the site is a popular place to conduct dive training for new divers because of its sandy, unobstructed bottom and visual interest. Modern objects such as cans and bottles are found on the site indicating that people have visited

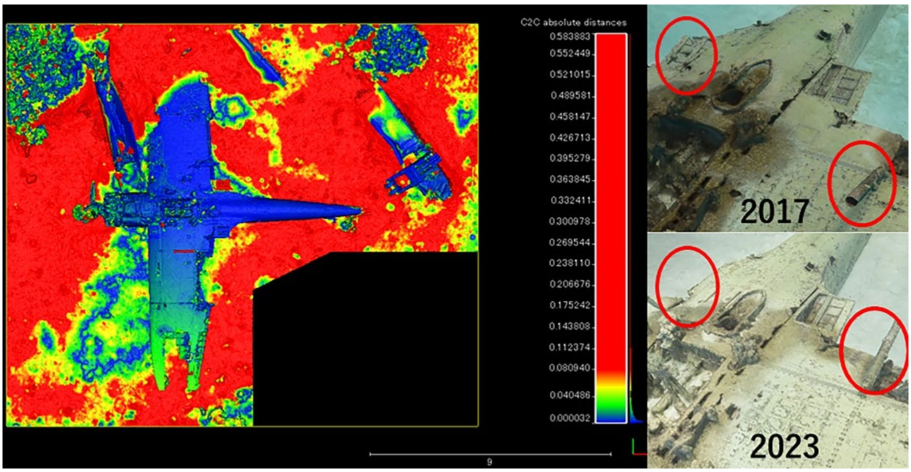

Fig. 18 Comparison between 2017 and 2013 on Aichi E13A

the site and left debris. A 1990 photograph of the site shows there once was a memorial offering of a sake bottle and stupa near the propeller providing further evidence that its significance is lasting and the site should be protected and preserved.

US Grumman TBM Avenger

A U.S. TBM Avenger lies inverted on the seabed with a scattered site distribution mainly consisting of the aircraft wingspan. It is located just inside the barrier reef near the north edge of the main channel entrance to Tanapag Lagoon in approximately 2.5–3 m (7–10 ft) of water (Fig. 19).

The Grumman TBF Avenger (designated TBM for aircraft manufactured by General Motors) was a torpedo bomber developed initially for the U.S. Navy and Marine Corps. It entered service in 1942 and saw its first action during the Battle of Midway (Tillman 1999, p. 6). Avengers played a significant role in the battle for Saipan providing offensive support which directly contributed to the victory. Grumman and Vought both competed for the contract to develop a torpedo bomber for the United States Navy (USN). Prototypes were made of both designs, although Grumman's TBF Avenger proved to be lighter, faster, and had folding "Sto-Wings," which was most attractive to the Navy because it could maximize storage space on an aircraft carrier (Drendel 2001, p. 2). The first round of production of Grumman's Avenger was completed in 1942, and the "Avenger" received its name from the Japanese attack on Pearl Harbor on 7 December 1941. When Grumman became focused on producing the carrier-based Hellcat fighter in 1943, production of the Avenger was transferred to General Motors (GM) where it was given the designation TBM Avenger (Drendel 2001, p. 2). Thousands of TBM Avengers were produced by GM during WWII.

Fig. 19 TBM Avenger. Photograph by Hiroyuki Tomura, 2023

Known as a rugged torpedo plane it was effectively used against surface vessels in the Pacific theatre. Most of their involvement consisted of bombing, ground support, anti-submarine patrol, and reconnaissance. Avengers participated in the initial air bombardments and strafing of Saipan preceding the ground troop landings (Hoffman 1950, p. 36). Avenger squadrons were focused on attacking Japanese aircraft carriers and combating Japanese aircraft units and played an active role in Rear Admiral Marc Mitscher's Task Force 58, which was involved in the Battle of the Philippine Sea (Tillman 1999, p. 27).

Four days prior to the Marine amphibious landing on Saipan on 11 June, Read Admiral Marc Mitscher ordered all four carrier groups to launch their planes and attack the Marianas. A total of 208 fighters and eight torpedo-bombers flew that afternoon (Tillman 2005, p. 55). Two Avengers guided 58 Hellcats from the carrier USS *Enterprise* for an attack on Saipan. In 98 min, they bombed Japanese aircraft on Marpi Point Airfield, Aslito, and a dirt runway at Chalan Kanoa and took on Japanese Zekes (Mitsubishi Zeros A6Ms), Kawanishi flying boats (Emily), and any other aircraft in the air (Okumiya and Horikoshi 1956). The U.S. pilots counted 98 kills while the Japanese reported 22 (Tillman 2005, p. 62). Also caught in the attack was the Japanese ship *Bokuyo Maru*, which was purportedly sunk in Tanapag Harbor, and *Keiyo Maru* which was damaged so badly it had to be beached (Farrell 2009, p. 291). On 12 June, 22 more kills were reported by U.S. pilots prior to turning their attention to shipping and military installations on land. Bombs were dropped on shipping facilities and other strong points and sugarcane fields were cleared with incendiary bombs (Farrell 2009, p. 291). On 13 June more Japanese planes were shot down including Betty and Helen bombers but the Japanese anti-aircraft gunners on Saipan and Tinian also scored kills against Avengers of the VT-16 Torpedo Squadron from the USS *Lexington*. Reeling from the attack, the IJN launched aircraft to meet the coming onslaught (Tillman 2005, p. 58). Continued bombings over the next two days resulted in approximately 150 Japanese aircraft destroyed (Wheeler 1983, p. 244).

Based on archival and historical documents it is known that two TBM-1C Avengers were lost during the battle for Saipan. They are Bureau Numbers (BuNo) 25537 and 17042. On 17 June 1944, Boyce Holleman piloted a TBM-1C (BuNo 25537), attached to VC-10 on USS *Gambier Bay*. Holleman, along with Aviation Machinist's Mate Second Class (AMM2) Jack D. Bacon and Aviation Radioman Second Class (ARM2) Howard M. Rivers conducted a bombing mission over Garapan, Saipan. They were struck by anti-aircraft fire and the plane caught fire. Holleman successfully ditched the plane and recalled that the two crew members, Bacon and Rivers, had both bailed out, and that one parachute had not opened. Holleman was found standing on its wing when he was later rescued. The plane was located on a reef in shallow water to the west of Mañagaha Island.

On 14 June 1944, Ensign (ENS) Russell G. Greene piloted a Navy TBM-1C (BuNo 17042) attached to VT-28, which took off from USS *Monterey* for a bombing mission to Saipan Island. During the mission, the plane was last seen diving over a target on Mutcho Point, Saipan. The pilot, Ensign Greene, Aviation Ordnanceman Third Class Edward J. Diskin, and Aviation Radioman Third Class Louis R. Speaks were reported missing in action on 14 June 1944.

The TBM Avenger site lies inverted on the sandy seabed in approximately 2.5–3 m (7–10 ft) of water (Fig. 20). The wing measures approximately 15 m (50 ft) long and is 2.5 m (8 ft) wide at the fuselage with the tail section missing. Nearly the entire fuselage is overgrown with coral. The aircraft's hydraulic landing gear is fully extended in its landing position and is exposed during extreme low tides (McKinnon and Carrell 2014). A 4.5-inch aerial rocket is in the port wheel well. A few isolated pieces of aircraft wreckage are scattered about the site within 20–60 m (65–200 ft) including portions of an observation port, a turret ring, possible

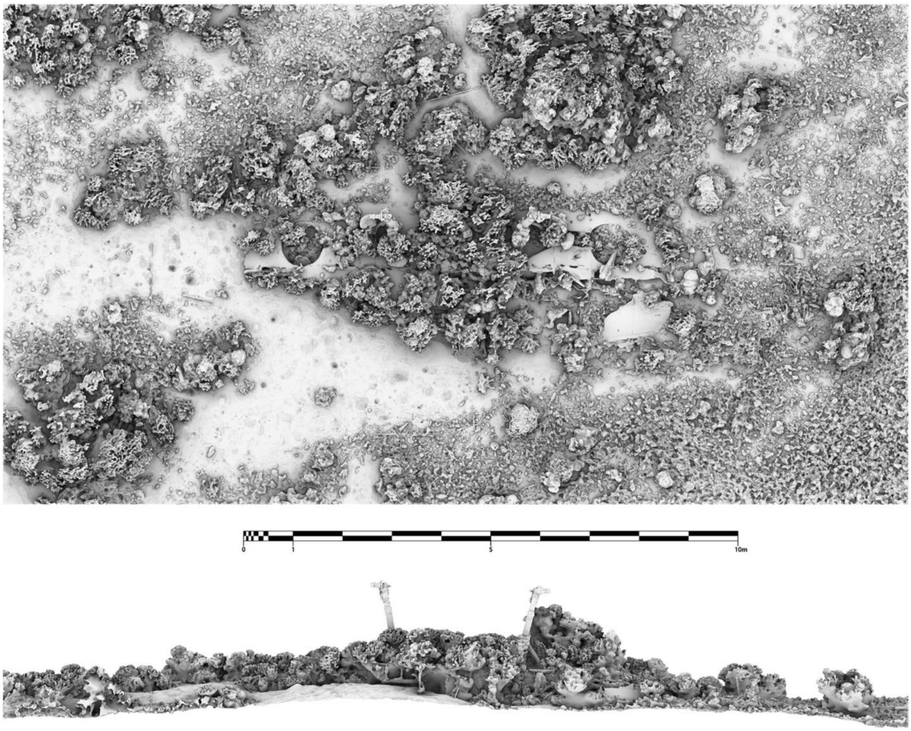

Fig. 20 Site plan from photogrammetric model of TBM Avenger, 2023

radio box, radial engine, propeller, and other unidentifiable aluminum parts. The engine and propeller are located approximately 60 m (200 ft) 345 degrees northwest of the aircraft body and a possible 500 lb bomb is partially buried next to the engine.

Due to its location on the barrier reef, a high energy hydrodynamic environment, it is subjected to tidal and wave action. This hydrodynamic environment has caused the disintegration of large portions of the wings and fuselage. The coral reef continues to grow in and around the wreck. Cultural features and impacts on the site are difficult to determine because the wreck has been majorly affected by natural processes. However, conversations with a local boat driver disclosed the use of the landing gear as a boat mooring for local surfers (Sheldon Preston personal communication 2010).

A comparison of the 2017 and 2023 model indicate that little has changed on the aircraft structure, however, in some areas sand accumulation of approximately 25 cm and in an area of 106 m^2 a total of 8.02 m^2 of sand has shifted. Additionally, coral growth has increased surrounding the aircraft (Fig. 21). While hard and soft corals do not typically attach and grow well on aluminum, it is likely that the concentration and abundance of coral will grow around the site enveloping it and obscuring it from recognition.

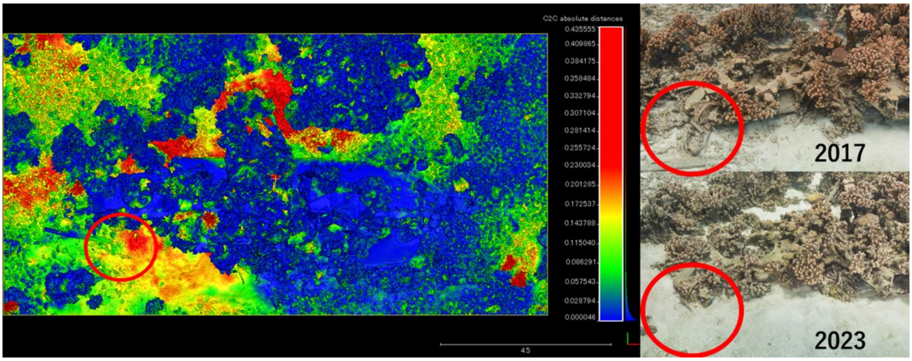

Fig. 21 Deviation analysis and changes on TBM Avenger site from 2017 to 2023. Note the sediment accretion from 2017 to 2023

Japanese Kawanishi H8K

A Kawanishi H8K Japanese flying boat, Allied code named "Emily," lies scattered over a wide area of sandy substrate in approximately 7 m (23 ft) of water in Tanapag Lagoon (Fig. 22).

The Kawanishi H8K Japanese flying boat was developed in 1938 by the IJN as a reconnaissance aircraft similar to the Kawanishi H6K "Mavis" flying boat already in production (Fredriksen 2001, p. 192). Design criteria were dependent upon maximizing both range and armament and the first prototype of the flying boat featured eight small

Fig. 22 Japanese Kawanishi H8K. Photograph by Hiroyuki Tomura, 2023

fuel tanks on the wings, six larger tanks within the hull, and three gun turrets on the nose, dorsal, and tail. These gun turrets housed Type 99 Model 1 (20 mm) cannon and 7.7 mm machine guns (Jablonski 1972, p. 231).

During WWII the IJN operated more seaplanes and floatplanes than any other nation. The Kawanishi H8K was the backbone of IJN aerial reconnaissance between 1942 and 1945, earning a formidable reputation among allied forces. Primarily used for reconnaissance, the size of the H8K also enabled bombing missions and transport runs as the self-sealing fuel tanks and armor plating facilitated defensive maneuvers (Fredriksen 2001, p. 192). Allied forces first encountered the aircraft in 1942 over Pearl Harbor. While cloud cover prevented the aerial assault, the H8K soon gained respect among allied forces as the aircraft were “extremely difficult to shoot down and had to be approached gingerly” (Fredriksen 2001, p. 192). Fredriksen (2001, p. 192) writes “the H8K was a formidable war machine. With a range over 4,000 miles, it was fast, maneuverable, and could cruise 27 h without refueling.” Jablonski (1972, p. 232) agrees, stating that the Emily, was “in fact, the fastest flying boat of the war.”

On Saipan, Kawanishi H8K flying boats were located at the Flores Point sea plane base and operated within the seadrome. At the time of U.S. pre-invasion, the Kawanishi H8K was actively used in the reconnaissance and protection of the island and surrounding seadrome. U.S. submariner reports from USS *Tunny* (Hurd 1944, p. 1) indicate that both H8K and H6K flying boats were running anti-submarine surveillance around the island in May 1944. These air patrols both targeted allied vessels and re-routed convoys out of harm’s way prior to the U.S. attack (Hurd 1944, p. 1). The historic record does document at least one H8K destroyed at its mooring in the lagoon (Hornfischer 2016, p. 77). No historic mooring has been found on the crash site of the H8K and two of the bent propellers suggest it was in motion when destroyed; as such, it is not likely this site represents the one recorded as destroyed at mooring. The destruction of these aircraft by the U.S. during pre-invasion and invasion air bombardments helped to prevent the Japanese from launching air assaults on U.S. troops as they landed on the beaches in Saipan. If these aircraft had not been destroyed, they would have likely caused significant damage to property and life during the U.S. invasion.

The aircraft wreckage lies inverted and disarticulated over approximately a 50 by 35m (164 by 114 ft) area inclusive of the main wing structure and disarticulated debris field (Fig. 23). The wing structure with engine nacelles is the largest recognizable feature. All four engines are present on the site. Engine 1 lies adjacent to its original nacelle on the port wing, while engines 2, 3, and 4 are located south of the aircraft wreckage. The cockpit is located north of its original position on site and sits upright with the pilot’s chair, controls, and steering column all accessible. Located south of the starboard wing is the bow turret with machine gun still in place. Other pieces of fuselage and unidentified aircraft wreckage are scattered on site. The fuselage bears some of its original grey and red paint patterning. Two granite monuments, one Japanese and one Korean, are located on the site in commemoration of the battle. There are two permanent moorings on the site to allow easy access to dive charters.

The aircraft is located inside the lagoon in a low energy environment. The site is impacted by algal and marine growth, evidenced by deterioration on the nacelles and a mucilaginous algal layer on aluminum alloy sheathing. Because it sits in the northern part of the lagoon, currents shift sand on the site, however, environmental factors have been categorized overall as minimally impacting the site compared to cultural disturbances (McKinnon and Carrell 2011, p. 68; Bell 2010, pp. 80–81).

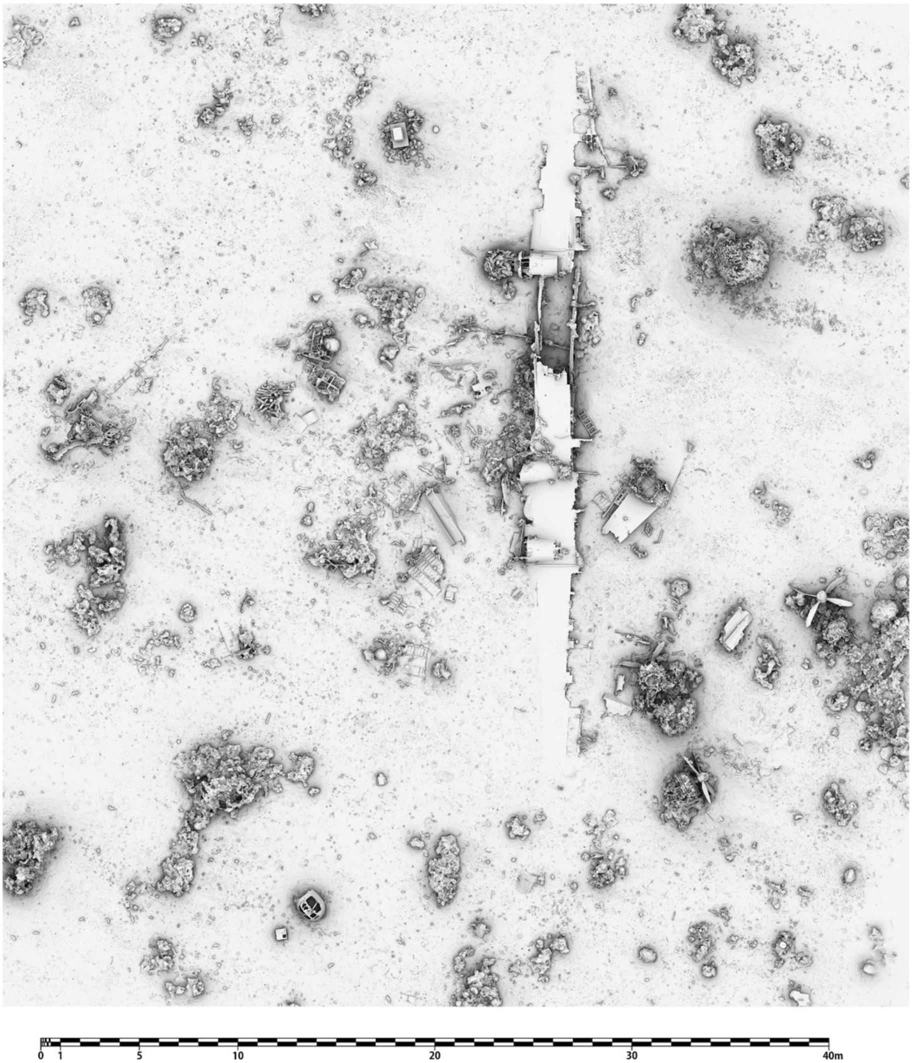

Fig. 23 Site plan of Kawanishi H8K, 2023

Cultural disturbances on site have been noted over the 15-year period of monitoring. McKinnon and Carrell (2011, p. 70) identified that the current placement of the cockpit is intentional and associated with recreational diving community photo opportunities wherein divers sit in the chair and are photographed. The cockpit control panel was repositioned between February and June 2010 and comparisons between 2017 and 2023 show the most amount of damage as the cockpit panel has been broken apart and incorrectly rearranged (Fig. 24). With each monitoring visit the cockpit configuration is altered and the chair has deteriorated significantly due to the force of heavy SCUBA tanks being seated inside. Smaller portable objects have been repositioned on site, such as a ladder-like rack propped onto the aircraft wing and oxygen bottles collected into a pile around the Japanese monument (McKinnon and Carrell 2011, pp. 70–71) (Fig. 25). The 2023 data also showed that

Fig. 24 Demonstrating changes on site between 2017 (top) and 2023 (bottom). Note the cockpit panel has been disarticulated and incorrectly reconstructed between dates

larger objects are being moved as well. The gun turret has shifted approximately 1 m and one of the engines has tilted approximately 45 cm. The movement of these larger objects are likely due to anchor drag as it would take a considerable amount of effort and more than one diver to move them via SCUBA (Fig. 26).

Two monuments are located on the site. The first monument is an upright square stone pillar featuring Korean inscriptions remembering the Pacific War. The stone was financed by a Korean television company, but little information is given regarding the relationship between the monument and the company. Korean people were conscripted to work for the Japanese during the war. The other stone monument is a Japanese monument inscribed with the words “Underwater War Memorial” (McKinnon and Carrell 2011, p. 72). The Japanese monument features stacked oxygen bottles that have been collected from the site and surround the monument.

Finally, there is other damage and looting of the site beyond artifact movement. A local dive shop owner possesses Kawanishi H8K identification plates likely removed from the wreck (Bell 2010, pp. 89–90). Graffiti etched into the algal coating on the aluminum has also

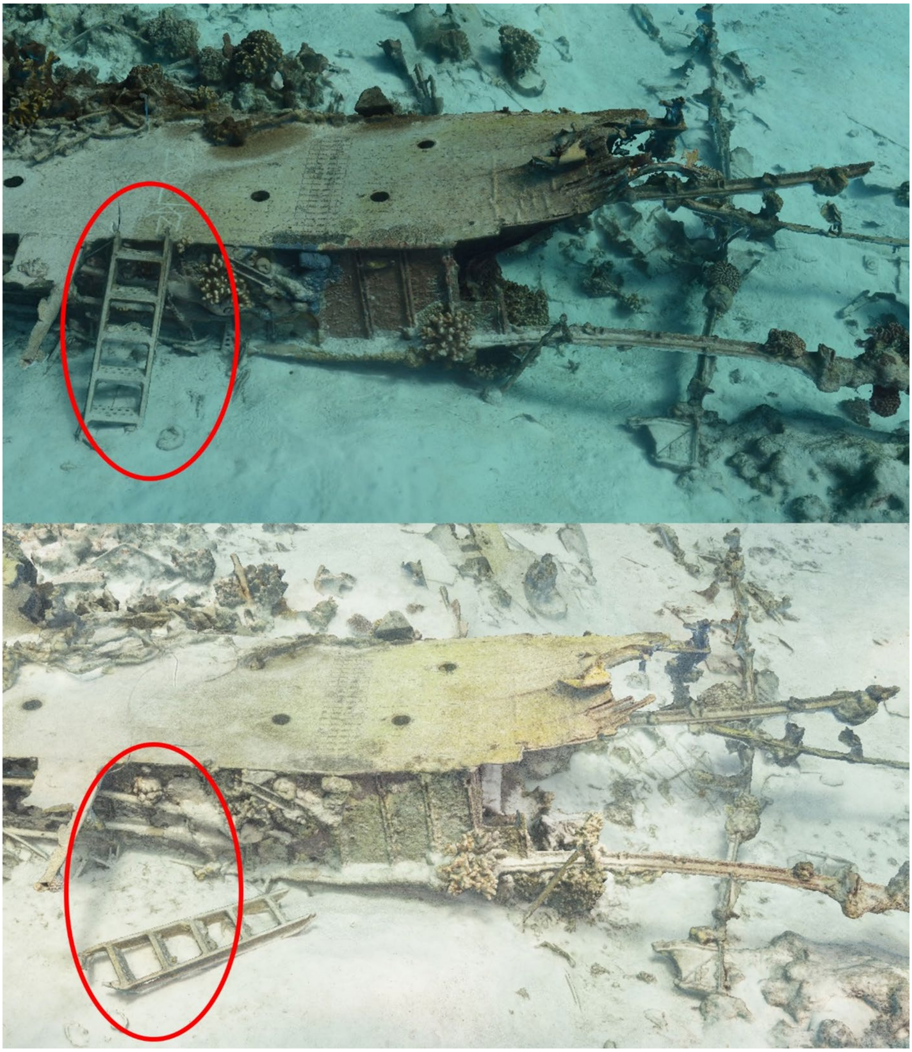

Fig. 25 Movement of smaller objects like the ladder can be seen

been recorded on site. And a portion of the nose cone was reported to the Historic Preservation Office after it was located on a beach. The piece was much too heavy to have floated up and it was likely placed on the beach by someone who no longer wanted to maintain it. The piece was recovered from the beach and placed back on site by the team on a monitoring visit.

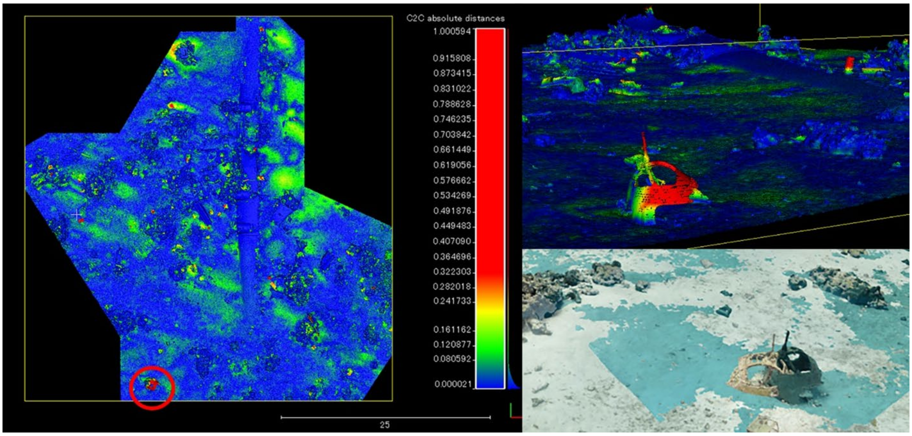

Fig. 26 Movement of gun turret on site

U.S. Martin PBM Mariner

A Martin PBM Mariner lies inverted on the seabed with a scattered site distribution consisting of the aircraft wingspan and other elements scattered further. It is located approximately 600 m (656 yards) SSE of Mañagaha Island and 100 m (109 yards) north of an exposed reef in approximately 7 m (21 ft) of water in Tanapag Lagoon (Fig. 27).

Dubbed the "Fighting Flying Boat," because of its service as a heavily armed reconnaissance flying boat, the Martin PBM Mariner was the second most used U.S. flying boat

Fig. 27 Martin PBM Mariner. Photograph by Hiroyuki Tomura, 2023

during WWII (Allward 1981, p. 116; Hoffman 2004, p. 1). Often overshadowed by the Catalina flying boats, the Mariner offered considerably more military capabilities (PBM Mariner 1950, p. 1). The U.S. Navy designated the Catalina flying boats as patrol bombers. Because of this distinction, the Navy needed a heavily armed flying boat to be used in bombing naval shore bases and in locating and attacking warships (Hoffman 2004, p. 1).

During WWII, the PBM Mariner served in numerous different roles for the Navy. The PBM Mariner, according to Shanline (1985, p. 33), "served the U.S. Navy as a long-range patrol bomber used in reconnaissance and for a variety of purposes ranging from cargo transport to ferrying the troops. One of its very important functions was rescuing airmen who were downed in the ocean or the survivors of surface vessels in trouble."

In response to the Navy's need for a two-engine aircraft that could attack, the Glenn L. Martin Company was granted a development contract to produce a prototype. The first service ready PBM-1 was delivered in 1941 (Hoffman 2004, pp. 3–6) (Fig. 4). Over the years, the Martin Company developed seven different models. PBMs had the same basic airframe with a wingspan of 36 m (118 ft), a height of approximately 8.3 m (27.5 ft), and a total length of approximately 24.3 m (80 ft) (Ginter 2013, p. 37). Depending on the variant, the Mariner had a gross weight between 40,513 and 58,000 pounds, a range between 1000 and 3650 miles, and a defensive armament of between four and six 0.50 caliber machine guns (Ginter 2013). Versatile in design and function it became the second largest used flying boat in the Pacific campaign.

The PBM-3D, thought to be the type of the wreck in Tanapag Lagoon, demonstrated numerous improvements over previous variants including stronger, fixed, strut-mounted wing floats and enlarged nacelles to increase bomb capacity. Powered turrets were in the nose, top deck, and tail, all with dual 0.50 caliber machine guns. 0.50 caliber gun mounts were also on both sides of the waist. Armor was added for better crew protection, and it was equipped with larger Wright R-2600–22 engines and four-blade propellers producing 1900 horsepower. An AN/APS-15 airborne radar system and antenna was mounted in a dome aft of the cockpit. The aircraft was separated into two levels and had five water-tight compartments. "Maximum speed was about 215 miles per hour; fuel capacity with droppable bomb bay tanks was 3,496 gallons and the range was [approximately] 2,400 miles" (Hoffman 2004, p. 6). The PBM-3D could carry eight 500-pound bombs, eight 325-pound depth charges, two Mark 13 torpedoes, or four Mark 13 sea mines (Ginter 2013, p. 42; Adamson 2020, pp. 21–22).

Initially, in Saipan, PBM Mariners operated in the sea outside of the lagoon, which made them susceptible to rough waters, but eventually their operation was brought into the lagoon on the newly established U.S. seadrome (Hoffman 2004, pp. xiii, 39). Mariners supported clean-up operations through August 1944 and provided anti-submarine screening by patrolling Saipan's waters (Hoffman 2004, p. 40). As the war in the Pacific continued, the Mariners ran "Dumbo" patrols, or open ocean rescue missions for B-29s taking off and landing in Saipan and Tinian. During these patrols, the Mariners approached the downed crews in the water and retrieved them. These missions saved the lives of many. These humanitarian missions of PBM Mariners reflect their larger role in the war effort. With capabilities of completing search and rescue missions along with bombing raids, the Martin PBM Mariner was a significant aircraft during WWII.

This site is likely one of two possible craft which have been identified from examining war records and war diaries from Saipan: Bureau Number (BuNo) 45262 and BuNo 45217, both of which were part of Patrol Squadron Eighteen and were PBM-3D variants. On 21 August 1944, BuNo 45262 was approaching a mooring buoy in the seadrome when the aircraft ran aground on a coral head and punctured its hull. The crew quickly abandoned due to the bilge pumps operating incorrectly and in doing so did not close the watertight doors or notify the nearby tenders (AAR Card, BuNo45262, Patrol Squadron Eighteen: August 1944). The aircraft flooded and was "bilged on the reef" (USS Bowditch War Diary: August 1944, p. 84). An attempt to salvage the vessel was unsuccessful (USS Bowditch War Diary: August 1944, p. 72). The crews disconnected the engines of the aircraft, removed salvageable parts, and "completed removal of surveyed PBM from coral reef off of seaplane runway" (USS Bowditch War Diary: August 1944, pp. 72, 80, 84). The aircraft and one of its engines were stricken after being "submerged for 44 h" (AAR Card, BuNo45262, Patrol Squadron Eighteen).

BuNo 45217 wrecked on 6 October 1944 while attempting take off on runway 23. The aircraft was on a test flight when it struck a large swell and the starboard wing tip dipped into the water. The pilot cut both engines and it came to a rest listing about 80 degrees when water started entering the starboard wing root. The plane capsized and sank nearly 3 h after the incident (AAR Card, BuNo45262, Patrol Squadron Eighteen). "Salvage attempts only resulted in the saving of gear that was readily removable from the plane before it sank" (Patrol Squadron Eighteen War Diary: October 1944, p. 2).

The aircraft wreck lies inverted in 7 m (21 ft) of water. The wreck is disarticulated and scattered over 100 m (328 ft) on the seafloor with a portion of the wing central to the site (Fig. 28). The port wing is largely intact and features an engine nacelle and exploded fuel tank, and the starboard wing is only partially present. No engines or propellers are found on the site. A large portion of the cockpit with operational gears and levers is located forward of the wing in situ. West of the port wing is a large patch coral and a large anchor, chain, and wire cable, which may or may not be associated with the site. Beyond the large coral head and anchor is a small portion of associated aircraft hull. To the east of the wing lies a portion of the tail with fin framing. Two gun turrets are located near the tail section.

The Mariner wreck is located in a low energy environment inside the lagoon protected by the barrier reef. There is a thin mucilaginous layer on the aluminum surfaces of the wreck and aluminum disintegration is evident on the wing. There are large coral growths around the site, with a substantial coral head located on the tail section. Anchor damage has been reported on site and 0.50 caliber ordnance and smaller artifacts have been moved from their original positions on the site into a pile. Locals reported in 1984 that the radio and other electronics with U.S. markings had been recovered from this site (Bell 2010, p. 53; McKinnon and Carrell 2011, p. 76). It is possible wrecking and/or post-war salvage has been conducted on the site, because of the missing propellers and engines (Bell 2010, pp. 95–101; McKinnon and Carrell 2011, pp. 82–86; Bell 2015, pp. 55–57; McKinnon 2015). Comparisons between 2017 and 2023 data indicate less changes to the site than other heavily visited sites like the Kawanishi site (Fig. 29). Coral growth has occurred and some of the wing structure shows more deterioration. The bomb bay door has shifted as well. Interestingly, this site is more protected from cultural impacts because it is in the Mañagaha Conservation Area which means no anchoring is allowed and only live boat diving is an option. Unlike the Kawanishi site which is outside the area and also has moorings making it more accessible to divers, the Mariner is more protected. The fact that this site has been susceptible to fewer changes over time indicates that divers do impact sites in Saipan.

Fig. 28 Site plan of Martin PBM Mariner, 2023

Conclusions

While the monitoring program is far from over and we expect to have another five years of data by 2028, photogrammetry has proven useful thus far in quantifying both natural and cultural changes on these important WWII submerged cultural heritage sites. The ability for archaeologists to record sites is force multiplied when using photogrammetry due to its accessibility, expediency, and ease of use. The addition of software that allows for comparison and deviation analysis value adds to what can be extracted from the data.

The next step in the process of analysis will be to compare in situ corrosion measurements with changes recorded in the photogrammetric models. This may reveal additional information about deterioration and potential risks as well as mitigation strategies for preservation. The move towards quantifiable data that can be measured over time is a significant step forward in the development of management strategies and photogrammetry proves to be an excellent tool in the toolbox of progress.

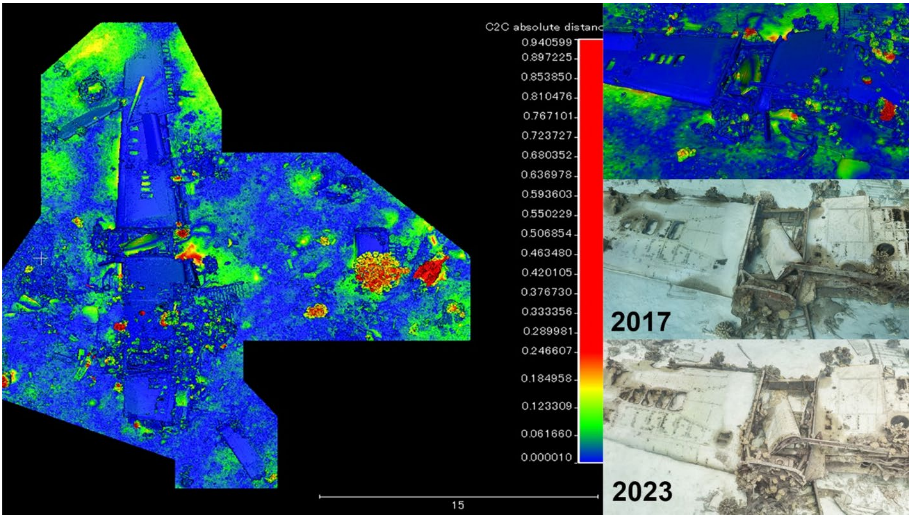

Fig. 29 Comparison of site between 2017 and 2023

The significance of these submerged WWII sites expands well beyond their importance as U.S. and Japanese historical sites. For the people of Saipan, they are legacies of a difficult past that play host to an incredibly rich maritime present. These sites are important for the island's tourism, fisheries, and recreation as they are integrated into a much larger Blue Economy on which the community relies. Their health and preservation coexist with the health and preservation of the community. As such, all aspects of their preservation should be considered in this light. While not addressed in this paper, several interdisciplinary data collection projects have run concurrent with the archaeological research including fish habitat studies, microbial environment characterizations, and heavy metal and contaminant studies. Combined these data sets will provide an improved picture of how these sites are both places of historical and environmental significance. Hopefully, this 15 years' worth of physical, chemical, biological, and archaeological data will contribute to their sustainability for yet another generation of divers, snorkelers, and swimmers.

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Author Contributions McKinnon and Yamafune wrote the manuscript and prepared the figures. All authors reviewed the manuscript.

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Data Availability No datasets were generated or analysed during the current study.

Declarations

Conflict of interest The authors declare no competing interests.

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