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SPECIAL SECTION

ENVIRONMENTAL PROGRESS & SUSTAINABLE ENERGY

Advancing sea turtle conservation in the South China Sea via U.S.-China diplomacy

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Abstract

The South China Sea is an important oceanic habitat for endangered sea turtles, which are facing anthropogenic pressures from the illegal wildlife trade, fisheries bycatch, debris pollution, habitat loss, and climate change. Compounding these threats are international disputes over territorial claims in the South China Sea, exerting a general disinclination toward regional collaborations to solve environmental issues. Since sea turtles are migratory animals that move through aquatic and terrestrial habitats, feeding in waters, and nesting on beaches under the jurisdiction of multiple countries, the species is an ideal ambassador to raise public support for international collaborations. Transnational communications to coordinate conservation efforts across borders provide a positive agenda of cooperation to build trust, creating a politically neutral platform to facilitate opportunities for diplomacy to reset and improve foreign relations, underscoring the value of sea turtles as a flagship species to reduce international tensions and bring nations together. For this reason, the U.S.-China EcoPartnership between Sea Turtles 911 and Hainan Normal University was formed to empower local communities to protect the ocean through sea turtle rescue, public education, and scientific research projects. Genetic research determined the geographic origins of illegally traded sea turtles, validating the uniqueness of the Paracel (Xisha) Islands rookery, and urging policymakers to establish a large-scale sea turtle nature reserve in the South China Sea. To define boundaries of the proposed marine protected area, sea turtles were tracked with satellite telemetry delineating their migratory routes and habitats across multiple countries, underscoring the importance of international collaborations. Debris pollution survey at a major turtle nesting beach in the Paracel Islands demonstrated that pollution is negatively impacting newborn turtle hatchlings and that regional cooperation in the South China Sea should promote the reduction and cleanup of marine debris. Laparoscopic surgery was performed on sea turtles for the first time in China to assess the gender ratio of the local population, which revealed a female biased ratio, indicative of the effects of climate change. A sea turtle rescue center was jointly established in which more than 100 sea turtles were successfully rescued and released by the international and local community, including students who won national awards for their volunteer service. Implementing grassroots initiatives for sea turtle conservation have

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become an ideal diplomatic channel to strengthen U.S.-China relations as several diplomats, including U.S. Ambassador Max Baucus, have engaged in people-to-people exchanges during public educational events. This international partnership serves as a case example in which current political disputes can be set aside to prepare future generations for the existential threat of biodiversity loss and climate change, while increasing peace, stability, and turtles in the region.

KEYWORDS
climate change, conservation, diplomacy, ecology, ocean, South China Sea, turtle

1 | INTRODUCTION

As herbivorous megafauna species, the green sea turtle *(Chelonia mydas)*, as well as other marine turtle species, have the important role of clipping sea grass beds to engineer more fertile habitat for fish species within the ecosystem. They feed on the grass by grazing it, promoting further plant growth, which in turn promotes more oxygen production and carbon absorption through photosynthesis. The process leads to more dissolved oxygen in the ocean for marine biodiversity to thrive, which results in more seafood products for economic trade, clearer water for increased tourism, and increased carbon storage for climate change mitigation. Green sea turtles also graze algae off of corals to promote healthier coral reefs, thus creating habitat that can accommodate a diversity of other marine species. The importance of conserving sea turtles is evident as these natural ecological services are reduced without a robust population of turtles, resulting in a degraded environment with negative impacts to the economy.

All sea turtle species found within the surrounding waters of China are included on the Red List of Endangered Species of the International Union for the Conservation of Nature (IUCN), appendix I of the Convention on International Trade of Endangered Species of Wild Fauna and Flora (CITES), and level I endangered species in China, which prohibits the killing, transporting, and trade of these animals.[1] By many accounts, green sea turtle populations are being diminished in the South China Sea, a marginal sea located south of China that extends into the Pacific Ocean. Despite legal protection under national laws and international treaties ratified by China, sea turtles are illegally traded for their eggs, meat, and shells in the Asia Pacific region. Based on seizure reports, Hainan, an island province in Southern China, is considered a crucial landing and selling point of marine turtles, as the island has become the epicenter of distribution to the larger national market.[2] By 2012, this unsustainable harvest had reduced all known sea turtle nesting activity in China to near zero, in particular, Guangdong province and Hong Kong.[3] While the notion of impending sea turtle extinction in China loomed, sea turtle nesting activity was discovered in 2016, with preliminary records of at least 150 nests in the Paracel (Xisha) islands of the South China Sea, renewing hope for the endangered species.[4,5]

Similar to what China is facing today, in the 1970's, sea turtle populations were exploited for consumption to near extinction levels in Hawaii.[6] Since the enactment of the U.S. Endangered Species Act (ESA) in 1973, America has experienced population recoveries of marine mammals and sea turtles.[7] After about 40 years of sea turtle conservation efforts, the green turtle population in Hawaii has increased 5% annually.[8] Because people are able to observe sea turtles frequently in nature when swimming or walking along beaches in Hawaii, the turtle exploitation history and succeeding population recovery in the U.S. is an inspiring conservation case example to share with China.

In June of 2015, Sea Turtles 911 and Hainan Normal University joined the seventh meeting of the U.S.-China Strategic and Economic Dialogue in Washington D.C., to discuss cooperation on climate change, ocean conservation and wildlife trafficking.[9] As a result, the U.S. Department of State and China's National Development and Reform Commission formed a U.S.-China EcoPartnership on behalf of sea turtle conservation.[10,11] The main goals of the partnership are to conduct turtle conservation research to monitor current and future ecological risks and disturbances; build a sea turtle rescue center to rehabilitate sick and injured turtles; and implement public educational outreach activities to empower local communities to save sea turtles in the Asia Pacific region.[12]

2 | ACHIEVEMENTS THROUGH THE PARTNERSHIP

2.1 | Sea turtle rescue and education center

Leveraging Sea Turtles 911's expertise of operating the floating sea turtle hospital in Hainan,[13] one of the greatest milestones of the bilateral partnership was the establishment of a rescue center for sea turtles at Hainan Normal University.[14] As the only sea turtle rescue facility in the world to be located within the premise of a college campus, students have convenient on-campus access to engage in volunteer work opportunities with sea turtles throughout the year. The success of the rescue center lies mainly on the efforts of student volunteers, who care for the turtles on a daily basis. Sick and injured turtles are medically treated at the center for fishing and boating related injuries, malnourishment, and diseases from the illegal wildlife trade, as well as the accidental ingestion of plastic pollution.[15] The rescued

turtles are released into the ocean upon recovery, during which public events are held to raise awareness for wildlife conservation.

Since 2014, American officials, including U.S. Consul General Jennifer Galt, have been supporting turtle conservation in China as an opportunity for public diplomacy.[16] Most notably, in 2016, two rescued sea turtles named *Harvard* and *Yale* were released with U.S. Ambassador Max Baucus.[17,18] In subsequent years, the rescue center has hosted U.S. diplomats, including U.S. Consul General Charles Bennett[19] in 2017, and U.S. Consul General James Levy[20] in 2018, and the U.S.-China Policy Foundation[21] in 2019. During these official visits, meetings were held with Chinese officials to discuss conservation plans while engaging in diplomacy to strengthen U.S.-China relations.

Aside from rescuing more than 100 injured turtles, the center serves as an educational outreach facility by hosting lectures for distinguished professors, such as Larry Crowder from Stanford University.[22] Guided by the EcoPartnership, students are trained to be volunteer conservation educators, teaching the public, including children and other students the importance of conserving turtles, and have been featured in interviews with local media.[15] Their community work was recognized with awards and scholarships from the National Youth Volunteer Service Competition and the U.S. State Department.[19,23] By teaching youth about sea turtles and the need for environmental conservation, the EcoPartnership builds long-term community capacity, increasing public involvement with turtle conservation campaigns. In follow-up to celebrity Yao Ming's conservation campaign with Sea Turtles 911 and Hainan Normal University,[24] another Chinese celebrity Liu Ye continued to raise community awareness for turtle conservation in China.[25] These continued public education efforts have left behind a legacy of turtle conservation, while spreading awareness for sustainable behaviors to address climate change throughout the community and into future generations.

2.2 | Satellite telemetry to map sea turtle migratory movements in the South China Sea

As sea turtles exhibit fidelity to specific breeding and foraging locations, an analysis of migratory movement of sea turtles would provide insight into where the potential habitats of sea turtles locate and the migration corridors between nesting and foraging habitats.[26,27] With knowledge on when and where turtle habitats are shifting, it would be possible to mitigate the impacts of climate change through the establishment of mobile marine protected areas,[28] which are dynamic and move along with the migratory patterns of sea turtles. Considering that the South China Sea is one of the world's largest shipping lanes for international trade, sufficient data that can elucidate the movement of turtles would enable policy makers to make scientific-based decisions to efficiently allocate resources to protect these migratory species, while developing economic activity in the region.

To determine the potential important habitats and migratory corridors for sea turtles in the South China Sea, nine green turtles were released from Hainan Island and tracked with the Advanced Research and Global Observation Satellite (ARGOS) system to acquire baseline data on the species migratory patterns and behaviors (Figure 1). It was discovered that the green sea turtles in the region have multiple migratory pathways foraging grounds. Three turtles (ID: 52695, 71919, 52693) remained in coastal waters near Hainan, while one turtle (ID: 53750) eventually traveled north to mainland China. Two turtles (ID: 37668, 50136) had migratory pathways toward the Paracel Islands, and two turtles (ID: 37669, 53758) showed migration behaviors toward the coastal waters of Vietnam. One turtle (ID: 58846) that had the longest migration, swam to Riau Island, Indonesia. On May 9, 2016, after signals from the satellite communications ended, this sea turtle was found stranded on a beach in the Songkla Province of Thailand. The Department of Marine and Coastal Resources (DMCR) in Thailand reported that the turtle had ingested plastic debris. This incident sheds light into the unseen harm and hazards that marine pollution has on sea turtles in the Asia Pacific region. Furthermore, two of the turtles (ID: 52695, 37669) that traveled along coastal Hainan and Vietnam were incidentally caught by fishermen as by-catch, substantiating another major threat to sea turtles.[29]

The baseline satellite data adds to the understanding about the foraging locations of neighboring international waters for additional protection. The data shows continuing support that Hainan Island and surrounding South China Sea are important habitats for green sea turtles, and additional neighboring countries Vietnam, Philippines and Indonesia are also crucial areas that share migratory turtle stocks and should be included in regional collaborations for sea turtle conservation. In 2012, Sea Turtles 911 and Hainan Normal University rescued and released a marine turtle from Hainan, which traveled over 2500 km to feed in the Palawan islands of the Philippines.[30] Evidently, these three cases of satellite tracked turtles traveling to other countries from China, strongly support the need for international partnerships, while empowering future generations to safeguard marine turtles for a healthier ocean environment.

The movement pathways, ranges, and timing in migratory animals such as marine turtles are being altered as the climate becomes warmer.[31] Continuous satellite tracking of sea turtle migration in the South China Sea should be conducted, so that researchers can detect changes in their migration activities and assess the impact of climate change on them. Our baseline data could provide insight into where sea turtle habitats are moving as the climate changes in the future and contributes in the establishment of mobile marine protected areas in South China Sea.

2.3 | Genetic analysis of the geographic origins of illegally traded sea turtles

Sea turtle confiscations that happen out at sea can give a general area that poachers are targeting, but it can be difficult to determine the impact on specific nesting rookeries. In addition to satellite-tracking, previous studies used genetic markers for a variety of wildlife forensic applications.[32,33] This type of forensic application has been useful in determining the general areas of origins for illegally harvested turtles

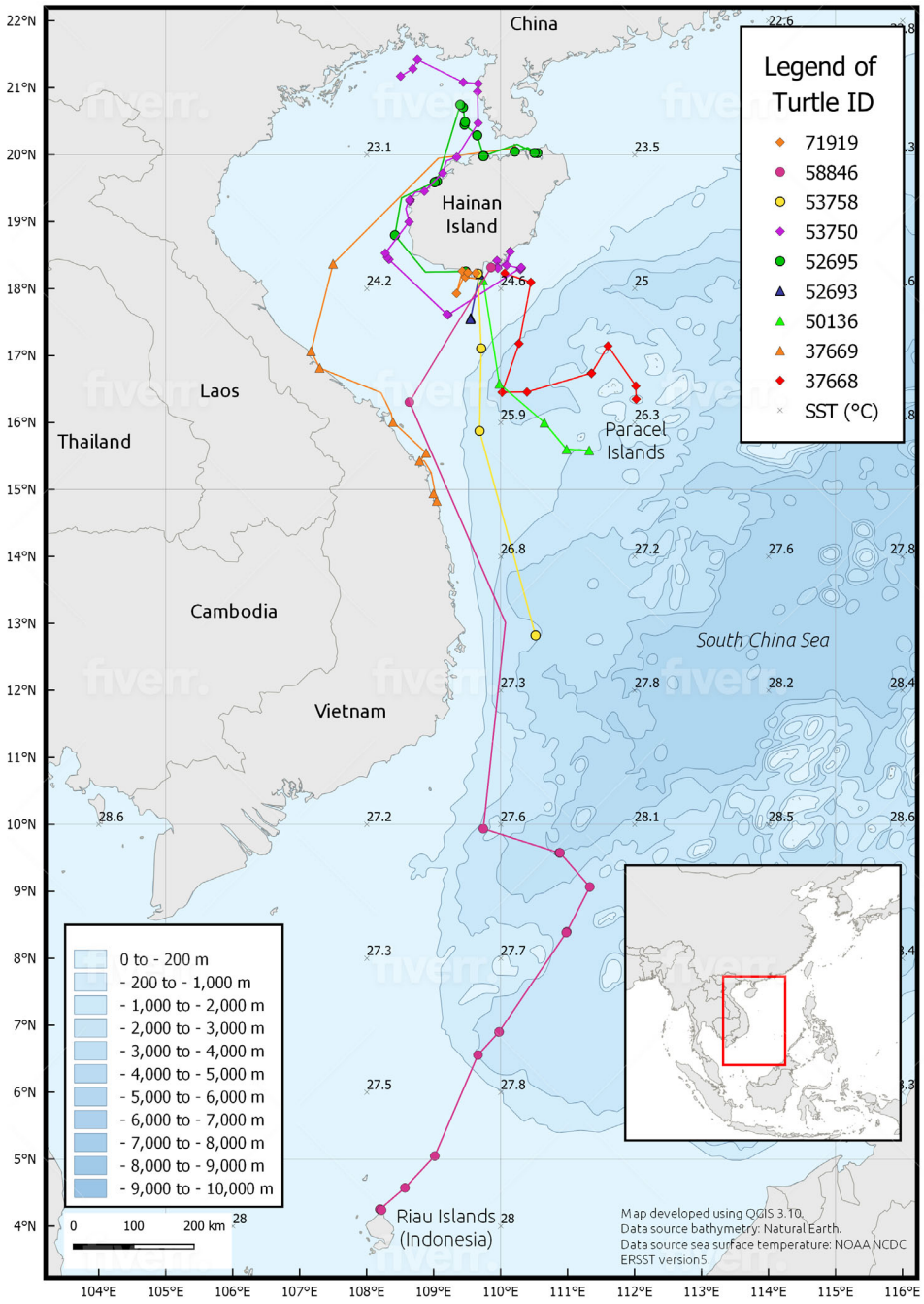

FIGURE 1 Map of migratory pathways of nine green sea turtles released from Hainan Island, China [Color figure can be viewed at wileyonlinelibrary.com]

and in identifying which nesting rookeries are sustaining the largest impact.[34]

To investigate the population origin of sea turtles being traded in Hainan, we sequenced the mitochondrial DNA (mtDNA) control region from 85 illegally traded green sea turtles rescued by our sea turtle rescue center. For reference-source data, we used previously published mtDNA haplotype data from Australasian rookeries,[35-37] and we collected and sequenced mtDNA from 16 sea turtle hatchlings born in the Paracel Islands of the South China Sea, a previously unsampled area. Ten mtDNA haplotypes were detected from our rescued turtles, and four haplotypes were identified from the hatchlings of the Paracel Islands rookery. As a result, we discovered that CmP19, an infrequent haplotype that has been found only in 10 green sea turtles previously, made up ~45% of our rescued samples and ~62% of the Paracel Islands sample, suggesting a potential association between CmP19 and the Paracel Island rookery. We performed a genetic mixed-stock analysis, which suggested that the rookeries in the Paracel Islands (~57%) and the Sulu Sea (~29%) are experiencing the greatest impact from illegal harvesting by fishermen from Hainan and neighboring countries.

Our research showed that the Paracel Islands population contains a unique genetic makeup compared with other studied rookeries, particularly the high frequency of the previously rare CmP19 haplotype. The current harvesting of green sea turtles by Hainan fishermen

affects not only protected local populations (Paracel Islands), but also distant populations (Sulu Sea) in protected international waters. Establishment of a large-scale Sea Turtle Nature Reserve in the South China Sea, including a special law enforcement team to monitor this National Marine Park, needs to be top priority to help curb illegal harvesting. The Paracel Islands represents a newly defined population, and conservation measures need to be taken immediately to preserve this distinct population.

2.4 | Laparoscopy and hormonal analysis to monitor climate change

Understanding reproduction processes of turtles is essential for conservation recovery efforts to bring their populations to sustainable numbers. Evolutionary theory indicates that male and female offspring should be in equal proportions, or reach an equilibrium because of selective pressures benefiting the rarer sex.[38] Since sea turtles become sexually mature to breed after 20 years of age, nest temperature data only forecasts how the gender ratio will impact the population 20 years later. Thus, it is important to determine the current female to male ratio of the current population to understand how the population will persist in the near future under the changing climate by assessing the genders of juvenile and sub-adult sea turtles in the local population.[39]

Due to the absence of external morphological characteristics that distinguish the sex of immature turtles, it is common to misidentify the sex of sea turtles without medical examination of the gonads.[40] Previous reproductive studies using both ultrasound and laparoscopy on immature female sea turtles noted the finer details afforded by laparoscopy in identifying smaller previtellogenic follicles (1–5 mm diameter), in which ultrasound could not.[41] Therefore, laparoscopy is a very useful technique to accurately determine the reproductive biology of sea turtles to assess climate change impacts on the population.

For the first time in China, laparoscopic surgeries on green sea turtles were safely performed in 2016. The minimally invasive procedure allowed direct visualization of the gonads of green turtles (Figure 2), resulting in a preliminary 3.8–1 female to male ratio, which indicates a skewed ratio delineating the effects of climate change.

In conjunction with laparoscopy, 138 blood samples from 40 green sea turtles were collected for hormone analysis to develop a baseline hormone reference interval (Table 1), so that future researchers can then use blood sampling as a more rapid method of assessing sea turtle sex without laparoscopic surgeries.[42] Blood samples were processed in an immunoassay analyzer with chemiluminescent technology to measure six sex hormones: follicle-stimulating hormone, luteinizing hormone, estrogen, progesterone, prolactin, and testosterone. The sex ratios of larger turtles would provide an older historical data, whereas smaller turtles would offer insight into more recent historical data. As more data is collected, modeling climate change effects on sea turtle population dynamics and the risk of feminization will improve conservation management plans to mitigate the impacts of climate change.

2.5 | Debris pollution survey of nesting beach at the Paracel Islands

Marine debris is an important factor threatening the survival of sea turtles. This anthropogenic threat not only affects the survival of sea turtles in the ocean, but also affects the reproductive process of sea turtles on shore.[43] Sea turtles are highly loyal to their birthplaces, so the environmental quality of their natal beach is critical to the successful reproduction of sea turtles.[44] Debris at nesting beaches not only interfere with the nesting process and nest site selection of female turtles, it can cause nesting failure, changes in nest distribution pattern,[45,46] and also hinder baby turtle hatchlings from crawling to the sea, increasing the risk of predation.[47,48] In addition, the enrichment of debris and microplastic can change the incubation temperature in the nest, thereby changing the sex ratio of sea turtles and affecting the structure of sea turtle populations; global warming will exacerbate this phenomenon.[49]

The Qilianyu Islands, a subgroup of islands in the northeastern part of the Paracel (Xisha) Islands, is the largest existing nesting site

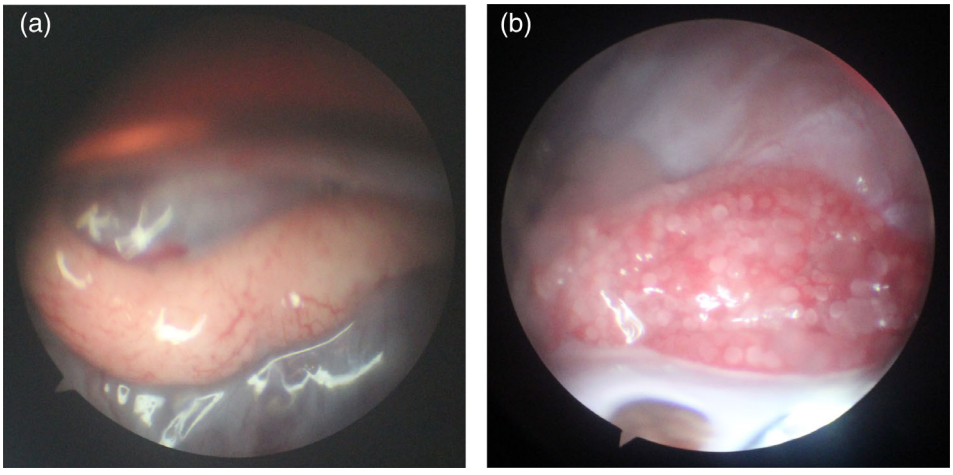

FIGURE 2 Laparoscopic view of sea turtle gonads. (a). Smooth, reticular testes indicate male gender; (b). Round ovaries resembling a cluster of grapes indicate female gender. (Photo F. Yeh) [Color figure can be viewed at wileyonlinelibrary.com]

TABLE 1 Reference interval (RI) for hormone parameters calculated utilizing the mean and standard deviation

Hormone parameter	Female Reference interval (mean)	Male Reference interval (mean)
Follicle-stimulating hormone	0.01–1.08 (0.068) IU/L	0.01–0.04 (0.019) IU/L
Luteinizing hormone	0.01–1.37(0.084) IU/L	0.01–0.39 (0.045) IU/L
Estrogen (estradiol)	2–231 (55.658) pmol/L	4–118 (40.272) pmol/L
Progesterone	0.01–2.94 (0.656) nmol/L	0.03–1.36 (0.641) nmol/L
Prolactin	0.01–247.75 (29.844) mIU/L	0.01–42.98 (8.715) mIU/L
Testosterone	0.01–4.71 (0.307) nmol/L	0.02–18.78 (6.91) nmol/L

Note: The RI was calculated using the MedCalc software (version 12.5.0).

for green sea turtles in China. Although this island is far from the mainland and relatively isolated with a small human population, debris pollution is still a major issue. Therefore, we conducted quantitative investigation on the beach debris and microplastics pollution on six islands of Qilianyu in 2019. Our studies on the status of environmental pollutants provide basic research information and baseline reference for conservation management plans, which would help protect and restore nesting beaches for green sea turtles in the South China Sea.

Microplastic pollution was found to be prevalent in the surface sediment of the nesting beach in Qilianyu, with an average abundance of 2349.78 ± 2075.11/m^2. The microplastic shapes mainly included foam, plastic particle and fiber, with foam and plastic particles accounting for about 90%. The average particle size of microplastics ranged from 0.01 to 5 mm, and the size distribution ratio of microplastics was mainly concentrated at <0.33–1 mm. White is the most common color of microplastics, accounting for 57.86%, while black is the next common color. Microplastic pollution not only exists on the surface of the nesting beach, but also at the bottom of turtle nests (about 60 cm deep). Considering that microplastics may cause adverse potential impacts on sea turtle nesting grounds, such as increased beach temperature and enrichment of pollutants,[50,51] the relationship between microplastics and the hatching success rate of sea turtle eggs should be further studied to accurately measure the impact of beach microplastics on sea turtle reproduction.

Overall, beach debris consisted of plastic, metals and glass, with the majority being plastic, accounting for 82.07% in quantity and 45.98% in mass. The average density of beach debris was 0.38 pieces m^{-2}, and the average mass density was 7.66 g m^{-2}. Compared with other sea turtle nesting beaches, the average quantity and density of beach debris here was lower, but the proportion of plastic debris was extremely high. After categorizing the type of debris, we found that most was from household goods (74.33%), followed by shipping/fishing activities (9.11%). Based on the textual language imprinted on the debris, we inferred that the geographic source was primarily from Southeast Asian countries (82.02%), such as Vietnam and Malaysia.[52] Signs of debris disturbance to both nesting females and baby turtle hatchlings have also been witnessed during our survey (Figure 3). To better protect this important nesting ground, regional cooperation in the South China Sea should be strengthened to jointly promote the reduction and cleanup of marine debris.

3 | FUTURE PLANS

3.1 | Aging research to improve population models

The fundamental aspect of sea turtle management and conservation is the application of population models as a basis for making decisions and predictions on how environmental fluctuations, such as climate change, will impact the population. Age is one of the most utilized, basic demographic variables for population studies because age regulates basic aspects of the life cycle, and is important in estimating risk of species extinction.[53] However, population modeling of sea turtles is often hampered by the inability to accurately determine the age of individual turtles, especially wild animals.[54] Research studies typically use body size to estimate the age of wild turtles, but this superficial method is prone to error because turtles grow at varying rates dependent on nutrition and other environmental variables,[55] and growth in body size becomes negligible after reaching sexual maturity.[56] Skeletochronology has been traditionally used as the standard technique to age sea turtles by analyzing the growth rings on the humerus bone,[57] akin to aging trees by counting the cross-sectional rings of wood growth; however, this methodology is limited because of uninterpretable growth marks[58] and the requirement of dead turtles.[59,60]

For live turtles, advances in genetic technologies and epigenetic approaches in measuring chemical changes to the DNA through methylation are promising for studying age dynamics.[61,62] By analyzing DNA methylation data, an epigenetic clock has been developed to predict the biological age of humans,[63] and its applicability has been expanded to different species as a universal measure of aging.[64,65] Sea Turtles 911 and Hainan Normal University plans to develop turtle species-specific epigenetic clocks, which would represent a new frontier in age determination for turtle conservation research globally. With the ability to collect more accurate age data to refine population models, the U.S.-China EcoPartnership would improve demographic analyses for long-term population monitoring of sea turtles in the South China Sea and help give practical conservation management advice to local government.

3.2 | Basking behavior research and student volunteerism in Hawaii

Monitoring and surveying beach habitats are critical to understand the adaptive response of sea turtles to the changing climate. While

FIGURE 3 Debris pollution in the green turtle nests on the North Island of Qilianyu, Paracel Islands. (a). Plastic debris dug out by green turtle nesting; (b). Newborn turtle hatchlings entangled by discarded fishing net and trapped inside nest. (Photo T. Zhang) [Color figure can be viewed at wileyonlinelibrary.com]

the majority of green turtles around the world utilize beach habitats for only nesting purposes, green turtles in Hawaii use beaches for an additional purpose: physiological thermo-regulation.[66] However, due to increased temperatures from climate change, scientists have estimated that by 2039, the Hawaiian turtles will cease exhibiting this unique basking behavior on beaches.[6] Despite a possible correlation of climate change to this behavioral phenomenon, studies in sea turtle basking have been limited. Research goals would include identifying trends and tracking changes in sea turtle basking behavior, including new locations, times, and abundance. By learning how green turtles in Hawaii use this terrestrial adaptation as a survival strategy, scientists would improve their understanding of the relationships that might exist between certain climate variables, in order to enable finer time series forecasting of climate change impacts.

To implement the climate monitoring research, Chinese and American students would work together to collect data on the beaches with basking turtles. While doing so, students would engage in cultural and language exchanges, and volunteer in the local community by educating people who are observing the wild sea turtles. In 2015, Hawaii Governor David Ige visited China and expressed excitement about future opportunities for partnerships between schools in Hawaii and China to promote people-to-people exchange among students as they strive toward developing into globally conscious citizens.[67] The development of cross-cultural connectivity and goodwill in Hawaii through sea turtle research and volunteerism would enhance U.S.-China relations, while building capacity to monitor and mitigate climate change impacts.

4 | CONCLUSION

While the future of sea turtles remains bleak in the South China Sea, the recovery and growth of sea turtle populations in Hawaii serves as a beacon of hope. Since the establishment of this partnership in 2015, there have already been conservation achievements in both community empowerment and in current baseline data collection, as well as in scientific achievement. Both Sea Turtles 911 and Hainan Normal University are continually working to increase community level cooperation and education on sea turtle conservation practices. While sea turtles are vulnerable because of their transnational migrations across multiple countries in the Asia Pacific region, the U.S.-China EcoPartnership demonstrated how cooperation between nations can yield a synergistic effect on the conservation of a migratory species. We encourage other nations surrounding the South China Sea to enact multinational partnerships to create a strong collective effort for sea turtle conservation and climate change mitigation.

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AUTHOR CONTRIBUTIONS

Frederick Yeh: Conceptualization; data curation; formal analysis; funding acquisition; investigation; methodology; project administration; resources; software; supervision; validation; visualization; writing-original draft; writing-review & editing. **Liu Lin:** Data curation;

formal analysis; investigation; methodology; project administration; supervision; validation; writing-original draft; writing-review & editing. **Ting Zhang:** Data curation; investigation; methodology; project administration. **Robin Green:** Validation; visualization; writing-original draft; writing-review & editing. **Frances Martin:** Validation; visualization; writing-original draft; writing-review & editing. **Haitao Shi:** Conceptualization; funding acquisition; project administration; supervision; writing-review & editing.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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