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Role of *Tamarix* sp. roots as an underestimated biotic factor in compromising a *Caretta caretta* nest

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Abstract

The increase in the number of *Caretta caretta* nests identified along the Lazio region coast (Central Italy, Mediterranean Sea) and the short distance of these nests from the High Tide Line (HTL) is making nest relocation a frequent management practice. Despite the care taken during nest relocation, the choice of the relocation sites can be compromised by unforeseen biotic factors. This paper documents reproductive failure in a relocated nest caused by interaction with the root system of a specimen of *Tamarix* sp. The nest, relocated 9.56 m from a *Tamarix* sp., was excavated 61 days after oviposition, as it showed no emergence of hatchlings. Despite continuous monitoring of nest temperature and effective protection from storm surges, emergence success was 0%. Subsequent analysis indicated that lateral roots of *Tamarix* sp. had encircled and apparently caused depletion of fluids from 55 eggs, halting embryonic development, presumably prior to day 12 after oviposition. The roots had travelled 11.06 m in the direction of the sea, encountered the nest, and were associated with apparent water depletion from the eggs, suggesting that the roots may have used the egg fluids as a source of water, resulting in a potentially fatal water-competition mechanism. This evidence underlines the critical need to revise relocation protocols to include preventive analysis of backdunal vegetation and substrate surveys to identify extensive root systems, especially those of *Tamarix* sp., which may cause an unfavorable ecological interaction for sea turtle conservation.

Key words: *Caretta caretta*, dune vegetation, hydric competition, incubation, nest relocation, *Tamarix* sp.

Introduction

Recent research confirms an active movement of breeding loggerhead *Caretta caretta* (Linnaeus, 1758) sea turtles towards the western Mediterranean coasts (Hochscheid et al., 2022; Mancino et al., 2022). This expansion into new nesting sites raises questions about the environmental suitability of the beaches chosen by the turtles, the characteristics of which may differ from those of historical sites.

Reproductive success and hatchling survival are closely related to the incubation environment, which is regulated by crucial environmental variables such

as temperature, structure, and humidity of the sand, as well as gaseous exchange between the nest and the external environment. In coastal areas subject to anthropogenic pressure from urbanization, tourism facilities, beach nourishment, and light pollution, nesting females tend to lay their eggs closer to the sea (Witherington et al., 2011; Leader, Noam et al., 2024; Ernest et al., 2025). Such proximity to the sea exposes nests to an increasingly frequent risk of flooding (Amarouche and Akpinar, 2021), whether from wave wash-over or from a rising water table. By saturating the sand and filling its pore spaces, flooding impairs the exchange of gases and water between the egg and its surroundings (Ackerman, 1997), and is considered a critical threat, especially during the early stages of incubation (Limpus et al., 2021).

Nest relocation is one of the most widely used management strategies worldwide to mitigate the impact of flooding on reproductive success (Morisseau et al., 2025). Relocation performed within the 12-hour 'safety window' was shown to have minimal impact on hatching success (Parmenter, 1980). Nests are usually moved towards the upper part of the beach, in a direction perpendicular to the sea, and are brought closer to the dune or vegetation line; the strip of beach immediately seaward of this line is among the zones most frequently used for nesting by *Caretta caretta* (Wood and Bjorndal, 2000; Serafini et al., 2009; Lasala et al., 2023).

Relocating nests towards the dune is a practical solution (Rees, 2020) to increase their elevation and protect them from storm surges; however, this may lead to new challenges presented by biotic factors. Indeed, the vegetation growing on and behind the dune can itself become detrimental to nesting and incubation (Awale and Phillott, 2014). Plant roots can: 1) interfere with nest construction, sometimes causing the female to abandon oviposition (Wood et al., 2014); 2) directly penetrate nests and damage eggs during incubation (Margaritoulis, 2005, Hannan et al., 2007; Conrad et al., 2011; Shaver et al., 2020); 3) mechanically hinder the emergence of hatchlings by trapping them in their dense network of roots (Redding et al., 2024).

This paper aims to: 1. Document and describe the damage - often undetectable without thorough excavation - caused by a root system of *Tamarix* sp. to a relocated *Caretta caretta* nest, despite the selected relocation site being determined as a safe distance from the dune plant; 2. Draw the attention of sea turtle conservation practitioners to the need to monitor the presence of *Tamarix* sp. and other plant species with deep and extensive root systems; and 3. Recommend avoiding the planting of *Tamarix* sp. in the immediate backshore strip in rewilding or stabilization interventions on dunes and beaches, as this may be potentially detrimental to the hatching success of sea turtle nests.

Study site

The study site was located in the dune ecosystem of the Sabaudia beach, along the Tyrrhenian coast of southern Lazio, within the Circeo National Park, in the province of Latina (Fig. 1). The beach is characterized by fine, sandy sediments that form a continuous and dynamic dune cordon. This dune is home to typical psammophilous and halophytic vegetation adapted to extreme conditions such as saltiness, drought, and strong insolation.

The studied nest (LAZ25_N009), laid only 9.3 m from HTL, was relocated to a new site on a beach located 12.5 km to the north. LAZ25_N009 was placed next to another nest (LAZ25_N002) that had already been relocated as it was also at risk of flooding. At a later date, a third nest (LAZ25_N017), also laid too close to the foreshore, was relocated to this same site (Table 1).

The relocation area included dune vegetation; the closest plants were a specimen of *Achillea maritima* and one of *Thinopyrum junceum*, both located at 7.84 m from nest LAZ25_N009. Among the plant species present, there were also two young specimens of *Tamarix* sp., the nearest of which was 9.56 m from nest LAZ25_N009, while the other, larger specimen, was at 21.79 m (Fig. 2).

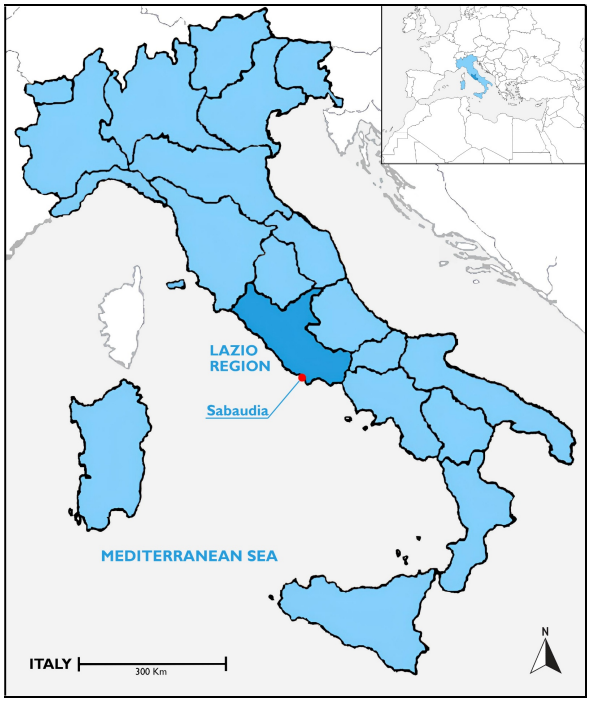
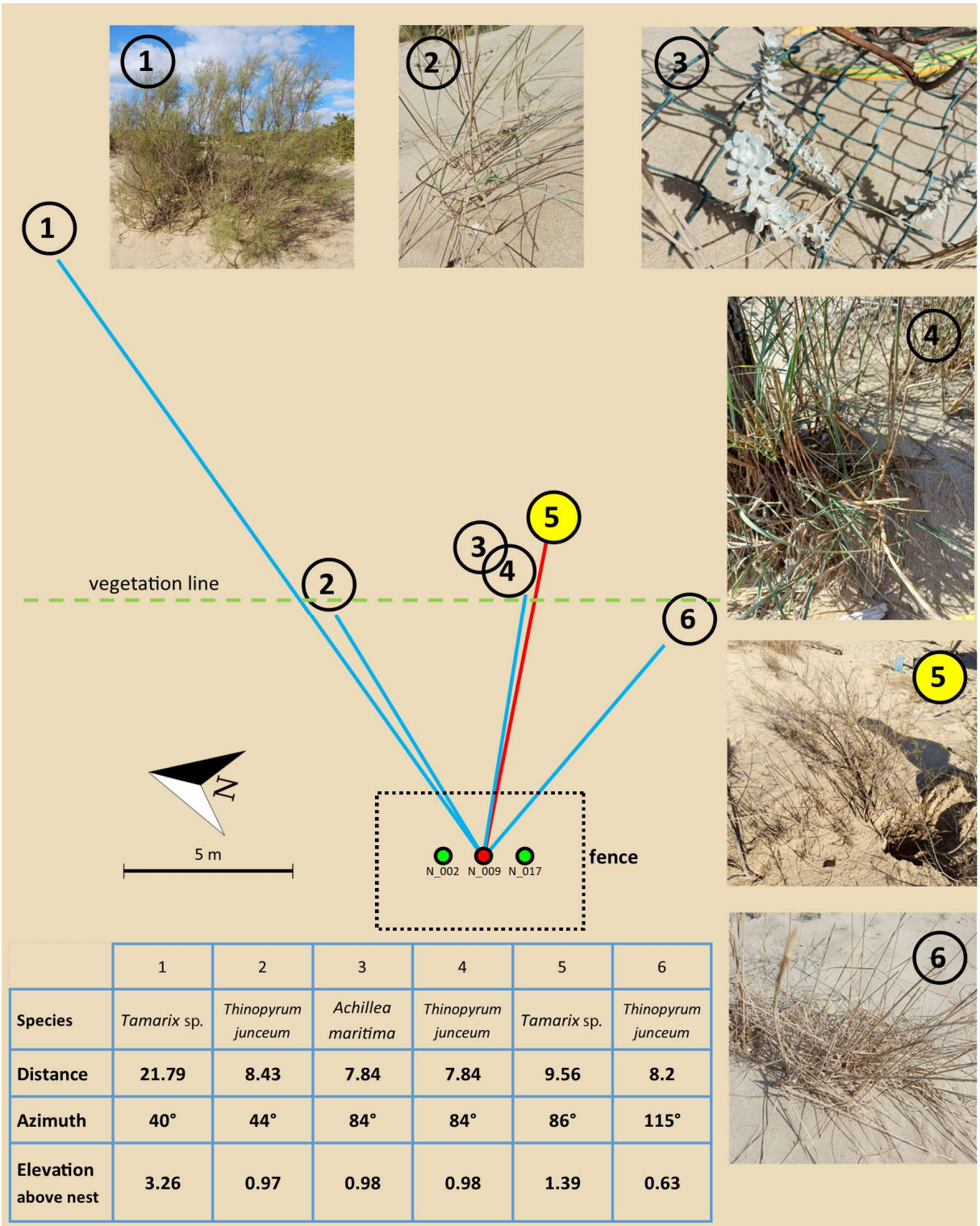


Figure 1: Area under study in central Italy, Lazio region.

Table 1: In situ and ex situ nest positions with geographic coordinates (latitude, longitude) and distances from High Tide Line (HTL).

Nest ID	Laying date	In situ position			Ex situ position		
		Latitude	Longitude	Distance from HTL (m)	Latitude	Longitude	Distance from HTL (m)
LAZ25_N002	13/06/2025	41.260794	13.031111	10.4			
LAZ25_N009	08/07/2025	41.337963	12.978216	9.3	41.260868	13.031249	22.9
LAZ25_N017	27/07/2025	41.257520	13.133201	5.5			



	1	2	3	4	5	6
Species	*Tamarix* sp.	*Thinopyrum junceum*	*Achillea maritima*	*Thinopyrum junceum*	*Tamarix* sp.	*Thinopyrum junceum*
Distance	**21.79**	**8.43**	**7.84**	**7.84**	**9.56**	**8.2**
Azimuth	**40°**	**44°**	**84°**	**84°**	**86°**	**115°**
Elevation above nest	**3.26**	**0.97**	**0.98**	**0.98**	**1.39**	**0.63**

Figure 2: Distance, azimuth and altitude of the six plants closest to the three nests. The colored circles in the box indicate the nests; the red circle is the nest subject of this study. Element number '5' is the specimen of *Tamarix* sp. involved.

Material and Methods

The researchers relocated the nest within 12 hours after oviposition, to a site selected according to standard but partially subjective criteria. These criteria were based on previous experience and were intended to ensure that the relocated nest was placed at a higher elevation than that of its original site to protect it from potential storm surges (Rees, 2020). Nest LAZ25_N009 was therefore relocated, as were LAZ25_N002 and LAZ25_N017, to a hatchery located at an average distance of 22.90 m from HTL and 5.70 m from dune foot.

Nest temperature was continuously recorded throughout incubation. In the absence of spontaneous emergence of hatchlings, nest LAZ25_N009 was excavated 61 days after oviposition, following the TartaLazio protocol of excavation 5 days after the predicted hatching date. During the inspection of the incubation chamber, roots were found around the clutch. In order to determine the origin and extent of the root system, manual tracing was carried out. Researchers followed the root and dug every two meters, both in the direction of the plant of origin (up to its base) and in the direction of the sea (up to the root tip).

Results

The increasing trend in the number of oviposition events along the Lazio coast, with 21 nests identified in 2025. The relocated nests, including the three nests in the hatchery on the Sabaudia dune, were effectively protected from flooding and storm surges.

Despite the effectiveness of this measure in mitigating flooding and storm-surge risks, the analysis of nest LAZ25_N009 revealed a negative outcome due to unforeseen biotic factors. Nest LAZ25_N009 recorded a hatching success of 1.8% and an emergence success rate of 0% (Table 2). During excavation, numerous roots were detected starting 20 cm below the surface. At the depth of the first egg (30 cm), roots had produced a dense network of rootlets encircling 55 out of a total of 56 eggs, albeit with different percentages of coverage (Figs. 3 and 4), and had extended down to the bottom of the incubation chamber, at a depth of 44 cm. The root system was found to belong to a specimen of *Tamarix* sp. The specimen of *Tamarix* sp. observed in the present study was a bush with six branches protruding from the sand, with a maximum branch length of 180 cm, a stem-base diameter of 24.9 mm, and a maximum height of 118 cm.

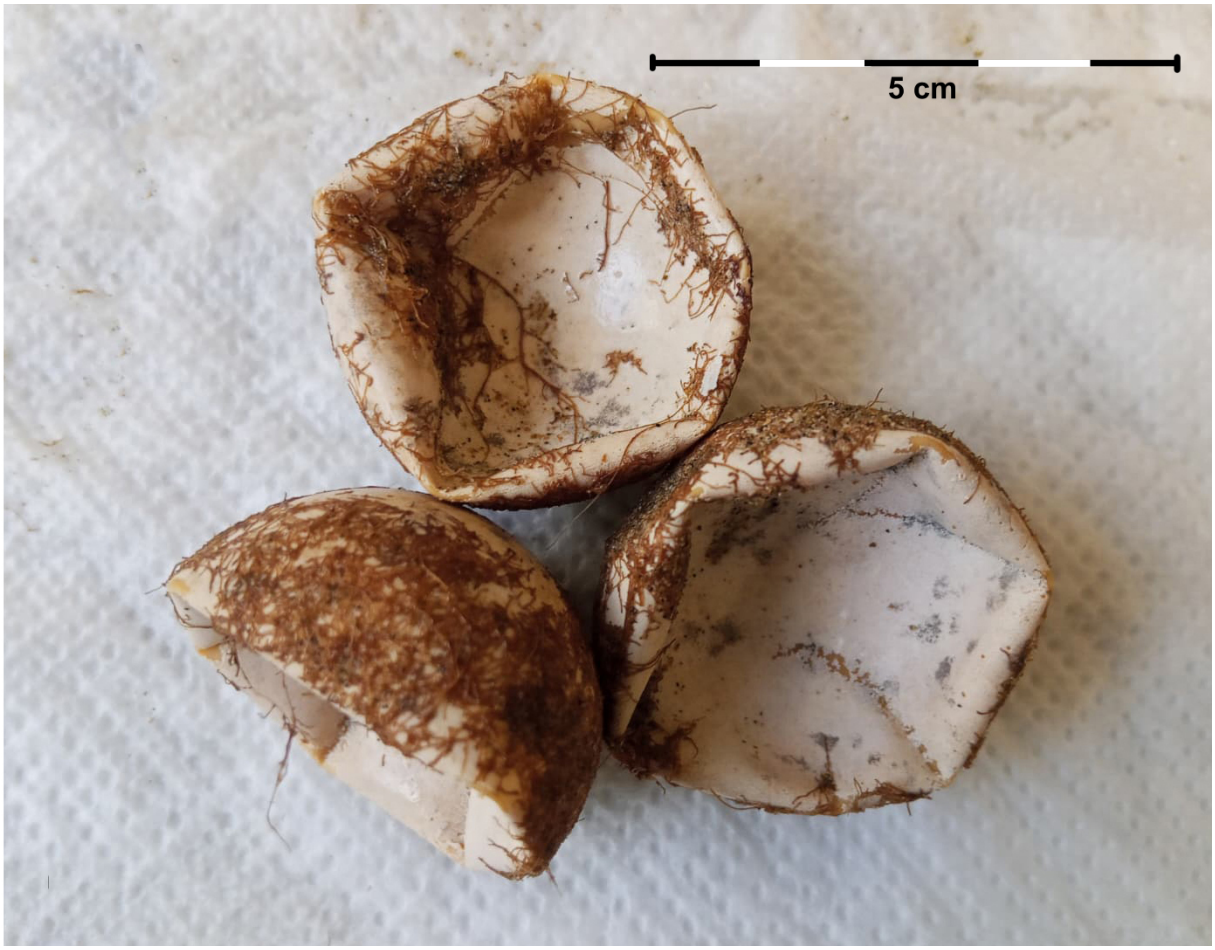


Figure 3: Dehydrated eggs with characteristic concave-convex shape.

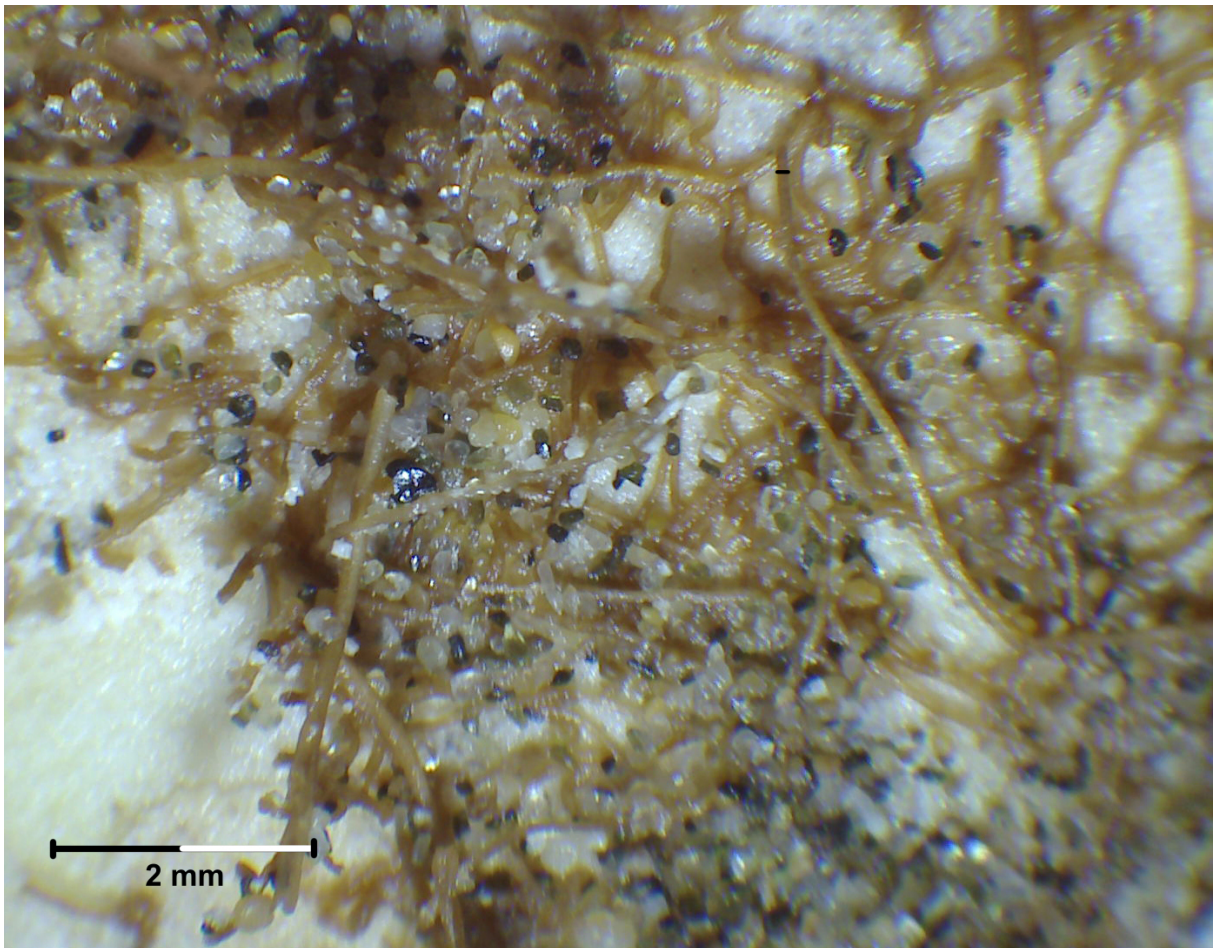


Figure 4: Rootlets of *Tamarix* sp. on the surface of the egg.

Table 2: Post-excavation reproductive parameters: laying date, excavation date, days elapsed, emergence success, hatching success, and asynchrony index.

Nest ID	Laying date	Excavation date	Days between laying date and excavation date	Emergence succes %	Hatching success %	Asinchrony index (A)
LAZ25_N002	13/06/2025	13/08/2025	61	50.5	50.5	1.84
LAZ25_N009	08/07/2025	07/09/2025	61	0	1.8	/
LAZ25_N017	27/07/2025	27/09/2025	62	0	63.2	/

Analysis of the affected eggs in LAZ25_N009 showed that the plant had apparently depleted the fluids contained within them, leaving the eggs dehydrated and with a characteristic concave-convex shape (Fig. 3). Only one egg, located in the middle of the clutch, contained a developing embryo that was pipping at the time of excavation. Without manual excavation, this hatchling would likely have been unable to emerge due to the dense and cohesive network of roots invading the nest cavity.

Deeper excavation allowed researchers to trace the lateral root, larger in diameter (Fig. 5), at a depth of 51 cm; it was this root that had generated the numerous ramifications responsible for the damage. The root, from the collar of the plant to its end, had a total length of 11.06 m, and extended beyond the nest by 1.5 m in the direction of the sea. The two other nests relocated to the hatchery were located only 1.2 m away on either side of nest LAZ25_N009.

Discussion

Relocating nests at risk of flooding to sites further from HTL is a valid management option to reduce the risk of flooding (Pike et al., 2015; Esposito et al., 2025), especially on beaches such as those in the Lazio region, where nests are often laid close to the sea. However, the choice of the exact spot, while following guidelines (Marine Turtle Conservation Handbook, Florida Fish and Wildlife Conservation Commission, 2016; Rees, 2020) and recommendations (Ware and Fuentes, 2017), remains subjective and must be made quickly.



Figure 5: Lateral root of *Tamarix* sp. taken near nest LAZ25_N009.

The case of nest LAZ25_N009 raises concerns about the potential impact of some dune vegetation species, even when located at a distance that appears to be safe from root penetration. Although the relocation of LAZ25_N009 at 22.90 m from HTL and 9.56 m from *Tamarix* sp. was apparently an appropriate choice, the extensive root growth of this plant was associated with the failure of hatching in this nest. The contrast with the two other nests relocated to the same hatchery further supports the relevance of the observed root interaction. Nest LAZ25_N002, relocated 25 days earlier and located only 1.2 m from LAZ25_N009, achieved an emergence success rate of 50.5%, albeit with an asynchrony index A = 1.84 (Gerosa et al., 2025). Similarly, nest LAZ25_N017, relocated 19 days later and also located only 1.2 m from LAZ25_N009, had a hatching success rate of 63.2% despite no emergence. Neither of these two nests was impacted by the root system of the *Tamarix* sp.

The *Tamarix* sp. (Tamaricaceae family) is known for its extreme resistance to drought, salinity, and wind. *Tamarix* species can develop deep root systems (up to 30 m) and extensive subsurface lateral roots that can reach 50 m in length (Baum, 1978). In addition, the *Tamarix* sp. has the ability to produce abundant adventitious roots when buried, which makes it an excellent dune binder (Baum, 1978). Precisely because of these characteristics, the *Tamarix* sp. is frequently used in naturalistic engineering and environmental redevelopment projects to stabilize sand and for windbreaks in coastal and rural contexts (Onori, 2009). A comparable concern has already been raised for Casuarina spp., widely planted as coastal bioshields yet shown to degrade sea turtle nesting beaches (Awale and Phillott, 2014).

The root that compromised nest LAZ25_N009 came from a young specimen located at 9.56 m and had travelled a total of 11.06 m. The association between *Tamarix* roots and sea turtle nest mortality has also been previously noted. Margaritoulis (2005) cited vegetation roots, particularly those of tamarisk trees (*Tamarix* sp.), among the apparent causes of in-nest hatchling mortality. However, that study did not expressly describe damage to eggs, making the present observation noteworthy because the roots were associated with apparent depletion of fluids from the eggs. Despite the dense network of encircling roots, stereomicroscope observation revealed a peculiar interaction with the eggshell. Unlike the effects reported for other damaging plant species (Conrad et al., 2011; Redding et al., 2024), the roots of *Tamarix* did not appear to directly penetrate the egg structure (Fig. 6); however, they appeared to cause localized thinning or indentation of the superficial calcareous layer (Figs. 7 and 8).

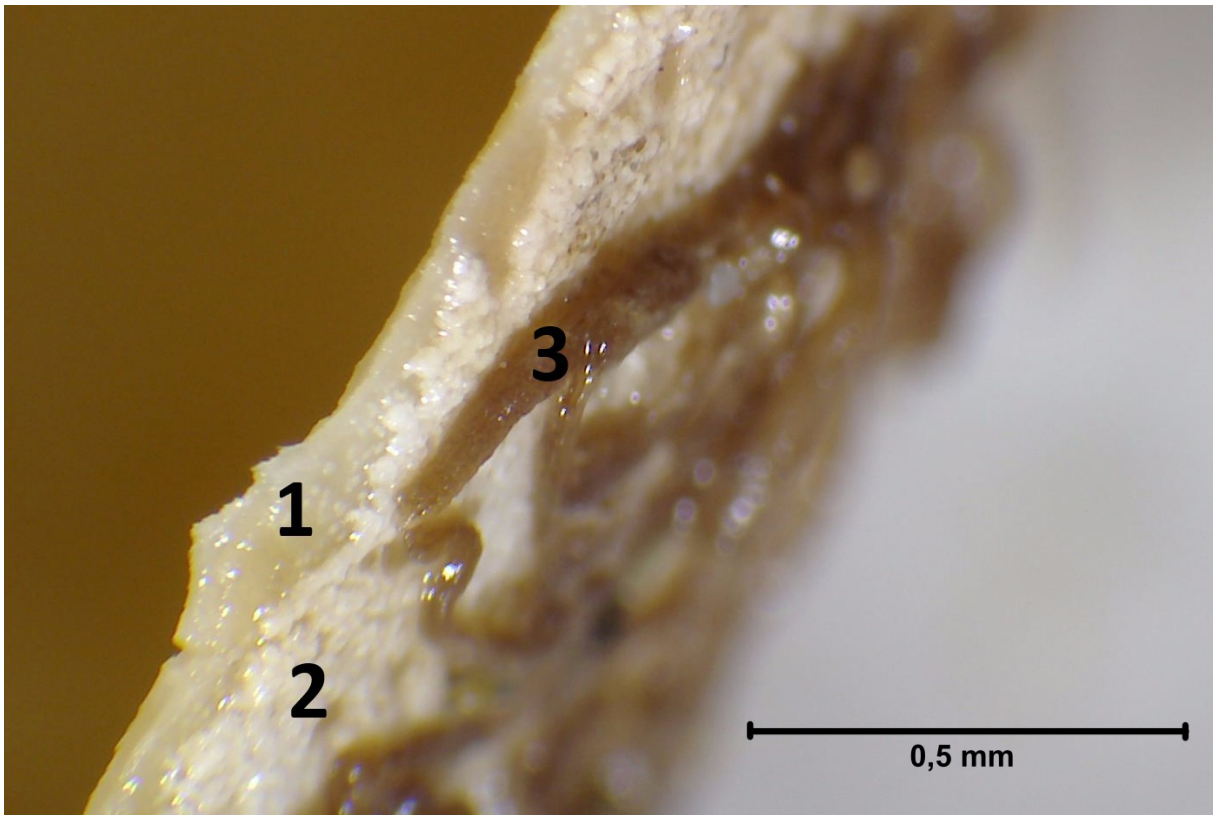


Figure 6: Cross-section detail: 1. Internal protein layer; 2. Outer calcareous layer; 3. Indented root hair in the calcareous layer.

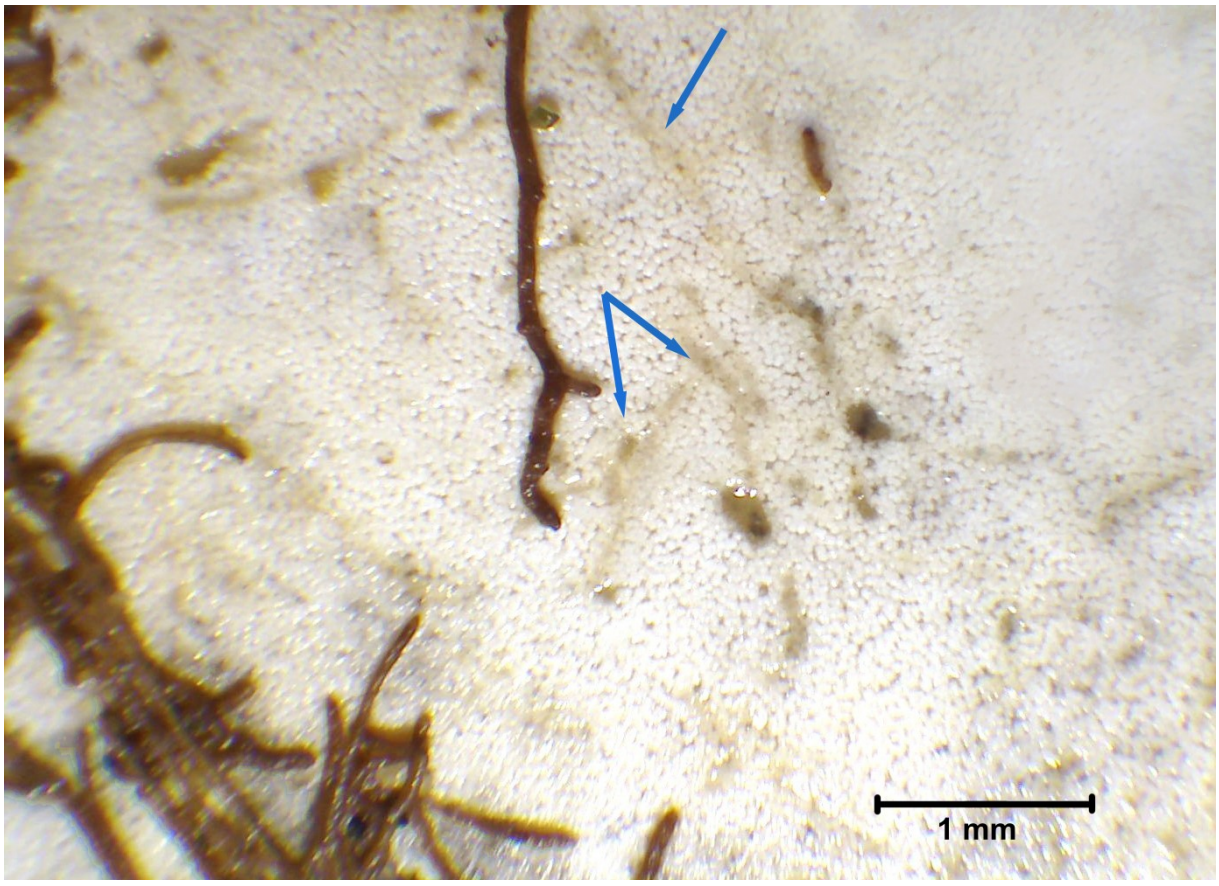


Figure 7: The arrows indicate the indentation furrows visible after removal of the root hairs.

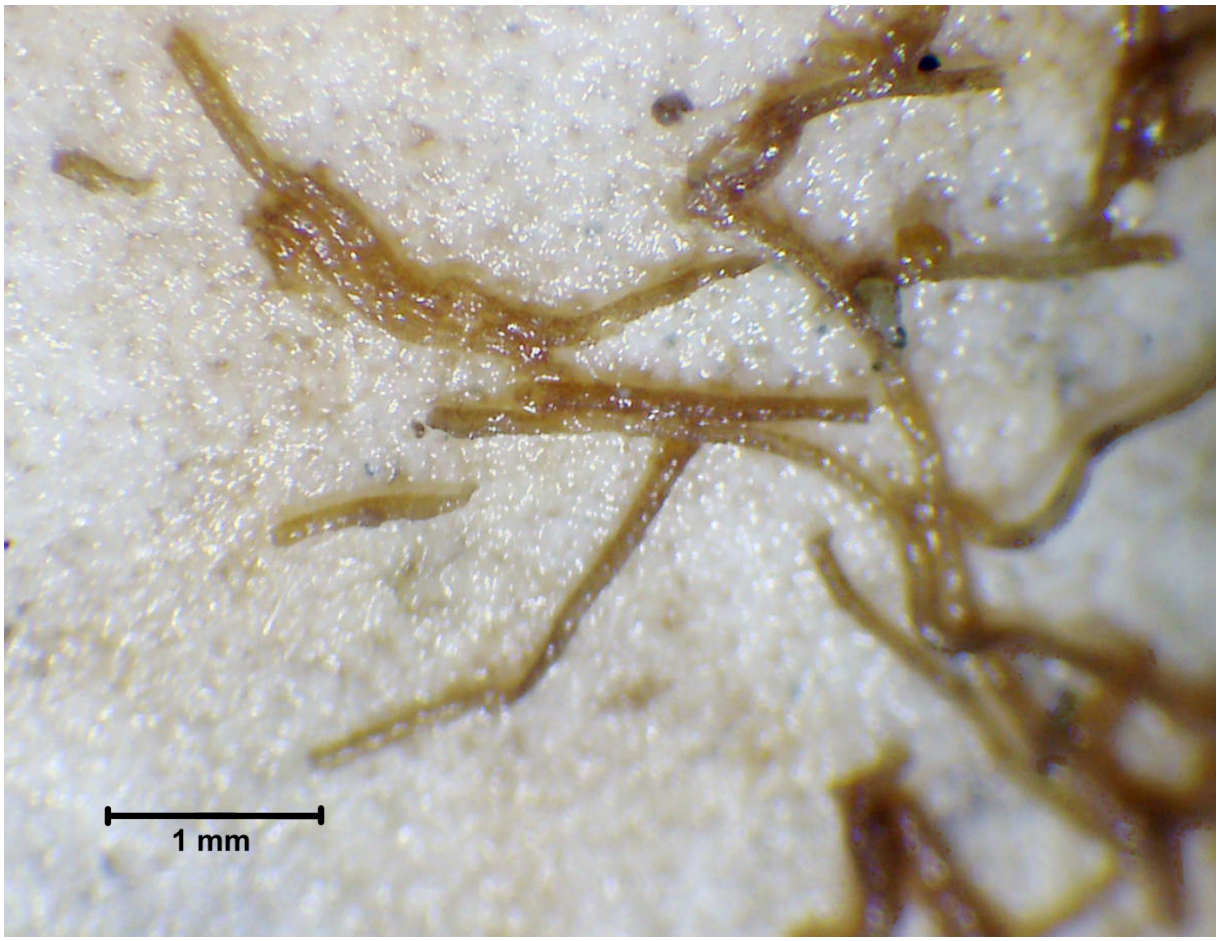


Figure 8: Indented root hairs in the calcareous layer of the shell.

Therefore, the main damage mechanism appears to have been water competition. Once the roots reached nest LAZ25_N009, the eggs may have acted as a localized source of water for the root system. Turtle eggs, due to their permeable shells, absorb water from the environment and have significantly lower internal water potential (-900 kPa (Ackerman, 1991)) than the sand around them (between -5 and -50 kPa (Ackerman, 1997)). This water gradient can make eggs potential sources of water for dune vegetation (Redding et al., 2024), particularly in drought-prone environments.

The observation that only one centrally located egg, which was not reached by roots, succeeded in developing an embryo whereas the peripheral eggs in contact with them were dehydrated, indicates that root interaction may cause embryonic arrest through water withdrawal. Assuming that the roots of *Tamarix* sp. effectively interrupted embryonic development, and adopting stage 16 of Miller et al. (2017) - corresponding to a 5–6 mm embryo with clearly visible eyes - as the diagnostic reference stage, no identifiable embryo at this stage was observed, even under stereomicroscopic examination. Furthermore, considering the relationship between embryonic development rate and sand temperature reported by the same authors, it can be inferred that the roots likely reached the eggs within twelve days after relocation.

In addition to absorbing water from the eggs, the roots would likely have mechanically prevented the emergence of the only developing hatchling found in the egg chamber, had this hatchling not been extracted during excavation (Conrad et al., 2011; Redding et al., 2024). The presence of roots may also influence the physical and biological characteristics of the substrate; however, no microbiological analyses were conducted in the present study, and therefore any contribution of fungal infection to the observed mortality cannot be assessed.

Conclusions

On the Lazio coast, relocation is an important management tool for the conservation of *Caretta caretta*. However, the experience of nest LAZ25_N009 showed that choosing a spot on the beach to relocate a nest based primarily on geomorphological and elevation criteria is not sufficient.

This observation illustrates how the root system of *Tamarix* sp. can compromise an entire nest, first by using the eggs as a source of water, and thus blocking

embryonic development, and later by mechanically preventing the emergence of the survived hatchlings.

It must be stressed that these findings derive from a single observation and, as such, do not permit statistical analysis; they should therefore be regarded as a preliminary report. Nevertheless, to the best of our knowledge this represents only the second documented case worldwide of *Tamarix* sp. roots compromising a sea turtle nest, which underlines its relevance and, at the same time, the need for further investigation and confirmation through the collection of additional data.

In light of this observation, and pending confirmation from further data, the following precautionary measures for relocation protocols are suggested:

1. Preventive analysis of backdune vegetation, in particular the presence of *Tamarix* sp. and other species known to develop extensive and deep root systems, although apparently distant.

2. In the presence of such plants, preliminary investigation of the substrate (possibly by non-invasive surveys) to identify the presence of active root systems before relocation.

3. Recommendation for rewilding or stabilization projects of dunes to not include the planting of *Tamarix* sp. in the immediate backshore strip, as *Tamarix* sp. would be potentially detrimental to the hatching success of sea turtle nests.

The effective conservation of *Caretta caretta* in Mediterranean coastal systems requires adaptive management based on the integration of multidisciplinary skills that combine conservation biology with plant ecology and pedology.

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Author contributions

G.G.: Conceptualization; Methodology; Formal analysis; Visualization; Investigation; Writing – original draft; Writing – review and editing. N.M.: Conceptualization; Methodology; Resources; Investigation; Visualization; Writing – original draft; Writing – review and editing. S.Z.: Conceptualization; Methodology; Investigation; Writing – original draft; Writing – review and editing. F.G.: Investigation; Writing – original draft. M.F., E.L., R.M., F.P.R.: Investigation.

Conflicts of interest

The authors declare that there are no conflicting issues related to this research article.

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