EXARC JOURNAL 2025/1
17 Articles | Open Access

Reviewed Article:

The Monoxylon Expeditions: The starting Points of a Nautical Archaeological Experiment

Persistent Identifier: https://exarc.net/ark:/88735/10786

EXARC Journal Issue 2025/1 | **Publication Date:** 2025-03-25

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The aim of this article is to present the starting points of the archaeological experiment named Expedition Monoxylon IV. The expedition, which took place in 2023, was an experiment with a replica of a dug out boat in the Aegean Sea. It followed up a series of earlier experiments (Tichý, 2016; 2020), one of which took place in the Western Mediterranean. Knowledge of the nautical characteristics of the three vessels and also their crews was gradually gained. The previous tests improved not only the replica but also our

knowledge of its behaviour on the sea. The 2023 experiment became the pinnacle of the expeditions. It is also useful to compare the practical results with the suppositions about the Bracciano boats (Mineo, 2015; Mineo, *et al.*, 2021; Caruso Fermé, *et al.*, 2023; Gibaja, *et al.*, 2024). Apart from describing the rationale of the experiment, this article will also answer the question of what the nautical characteristics of Bracciano 1 are.

> One of the surprises was the increase in speed in comparison to our earlier expeditions. It seems that the extra length allowed for faster travel in waves. The speed while paddling under normal conditions reached up to 5.5km/hour.

Introduction

Recently (Gibaja, *et al.*, 2024), boats dug from single tree trunks found in Lake Bracciano near Rome were classified, on the basis of their morphology, as boats suitable for sea navigation and therefore fundamental for the process of the Neolithisation in the Mediterranean. Such possibilities were considered not only because of the size of boat 1 from this site, but also because of other wooden artefacts found in the surrounding area (Caruso Fermé, *et al.*, 2023).

Description of the experiment

The proposal that the Bracciano boats could have been used for sea navigation was debated since their discovery. The lake could have been connected, via the Arone River, with the Tyrrhenian Sea (Fugazzola and Mauro, 2014). Later, this supposition was accepted as a fact (Mineo, 2015). The complexity of the vessel was supported by the presence of two artefacts with holes and a cut in the shape of "T" (Fugazzola and Mineo, 1995), which could have been used to anchor ropes controlling a sail, to connect two such vessels as a catamaran, or to fasten a stabiliser (Mineo, *et al.*, 2021). The excavation of the Early Neolithic village, where five variously preserved boats were found, revealed wooden paddles made from one piece of wood and an artefact interpreted as a possible steering paddle (Caruso Fermé, *et al.*, 2023). It is important to ask if these artefacts are truly proof of sea navigation. The original Expedition Monoxylon became accepted as an argument supporting the sea faring possibilities of the boat (Mineo, 2015). For the Expedition Monoxylon IV the boat based on Bracciano 1 was made even more accurately to reflect the original. The main aim of the 2023 expedition was to evaluate the sea faring capabilities of the Bracciano 1 boat.

It is important to emphasize that the 2023 nautical experiment best fitted the rules established by John Coles (1979, pp.43-48) the best. The material used(oak) corresponded (rule 1). During the building of the boat, while working on the interior, we dug 3 metres from the total 9 using authentic lithic technology (rule 2). We used modern technology to document the navigation: GPS, the accompanying boats instruments to measure strength and direction of the wind, and a dictaphone to record height and direction of waves, as observed relative to the accompanying boat (rule 3). The work output and performance of the vessel replica were noted (rule 4). We understand the results as only a supporting argument in the discussion on the navigation characteristics of Bracciano 1 (rule 7), though we consider them cardinal. The nautical experiment was carried out with thoroughness and honesty (rule 8). The repeatability of the experiment (rule 5) would be, in this case, very difficult because of the constant change of the weather conditions during the voyage. This, however, relates to Coles' requirement (1979) to not refrain from improvisation (rule 6) but to thoroughly record it.

Boat design

During the Expeditions Monoxylon, the design of the vessel developed as our knowledge did. At the beginning, in 1994, we built a hypothetical boat from a 6.2 m long poplar trunk. Theoretically, it was ready for sea navigation, with a raised bow and stern (See Figure 1). In the same year the Bracciano 1 boat was discovered (Fugazzola and Mineo, 1995). The publication of that find influenced the next boat from 1997/1998, which was built from an oak trunk (See Figure 2a). Because of the size of the available tree, it was only 9.2 m long in comparison to the original's 10.45m. The second boat was adjusted (thinned bottom and walls) in 2018 for the Monoxylon III Expedition (2019) (See Figure 2b). During 2022 we obtained a tree big enough to build a boat which was accurate, in size to Bracciano 1 (See Figures 4 - 13). Because of the close correspondence of its measurements to the original, we considered it as close a replica as we could achieve.

The design of the third boat was still partially hypothetical as the original was not fully preserved. The 11.5 m length of the replica fills in the missing part of the bow and also includes a 0.5m long 'wave breaker' (See Figure 9b) known from ethnographic parallels. Its absence would limit the capability of the boat to navigate in waves. The width of the original was followed, and it allowed for a comfortable seating of two paddlers side by side. The number and position of inner ribs was followed. From the point of view of the navigation, the height of the sides is the most important. The original's sides are preserved to between 44 and 65 cm (Gibaja, *et al.*, 2024). Because of the damage, the sides of the experimental vessel were reconstructed to a height of 75 cm. This had the most influence on the capability of the experimental vessel to navigate waves.

It is important to note that the length of the vessel restricts the influence of high waves. The difference was obvious from comparing the voyage of the first hypothetical vessel (See Figure 1) in high waves in 1995 when the boat lost speed between neighbouring waves, and the third vessel built according to Bracciano 1 where the length allowed it to span two neighbouring waves, so the vessel does not significantly lose speed.

Voyage route

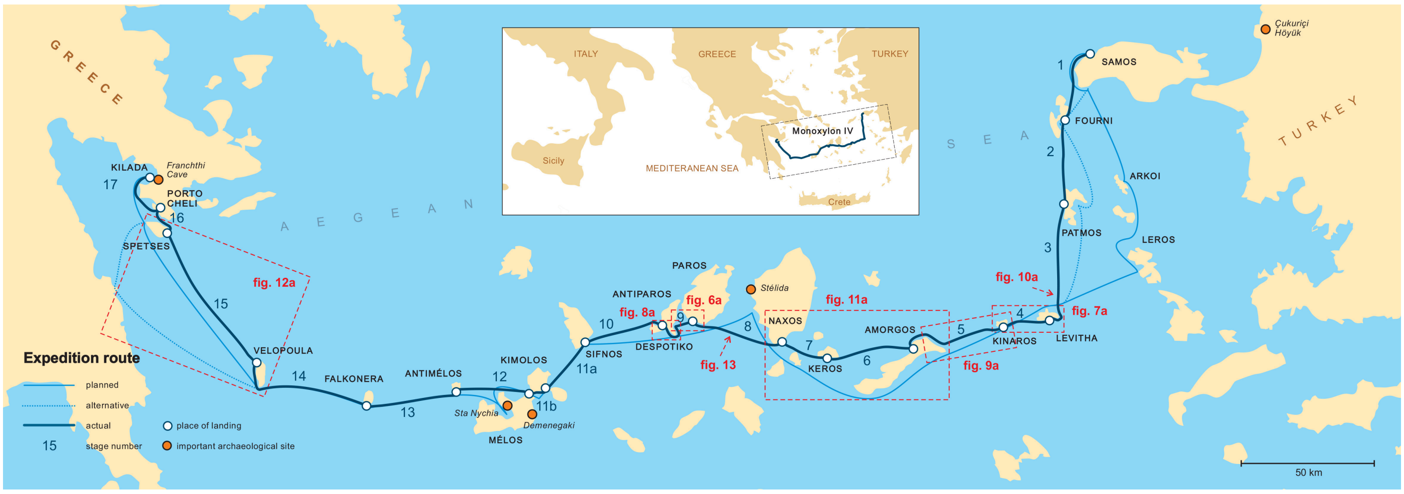

FIG 3. THE ROUTE OF MONOXYLON 4 EXPEDITION WITH MARKED STAGES AND LOCATION OF WAVE TYPES ALONG THE ROUTE. MAP BY ONDŘEJ ŠTULC.

The result of the experimental navigation was fundamentally influenced by weather conditions during the voyage. The more demanding conditions meant more exacting testing of the nautical characteristics of the replica. For example, the route and time of the year suitable for the Monoxylon III voyage in 2019 was chosen deliberately. The main aim was to cover a 100 km long stretch without landing. Therefore, we chose the calmest weather, which in the western part of the Mediterranean occurs mostly in May and June. The Monoxylon IV route was chosen to correspond with historical evidence (Early Neolithic site Çukuriçi Höyük (Horejs, *et al.*, 2015) with finds of large amount of obsidian from Melos - Melos - Franchthi cave with obsidian finds (Perlès, 1990) and evidence of early Neolithisation (Perlès, *et al.*, 2013). At the same time, we chose alternative navigation routes depending on the actual weather, so the navigation along the southern wind later changed to navigation in side waves. The middle part of the voyage could shelter from the wind along the southern coasts of the islands and the longest stage could, in the final phase before arrival on the Greek mainland, use the following wind (See Figure 3). The voyage aimed to land on the islands to sleep and rest during unfavourable weather (strong wind, high waves).

Powering and steering

The vessel was mainly powered by paddling. That corresponds with the finds from Bracciano (Caruso Fermé, *et al.*, 2023). At both sites, two types of paddles were discovered. One is a paddle with a long, narrow leaf, the other with a short and wide leaf. According to modern interpretation, the first one is intended for use in deep water, and therefore, it was chosen for sea navigation. The paddles were made from a single piece of ash wood. These paddles proved effective in waves and allowed for faster frequency of paddling (35 and more strokes per minute) than during earlier expeditions. This affected positively the overall speed, which was more than 5km/hour during the stages powered by paddling only.

We used a sail as a supporting propulsion, We attached it to a sailyard and a mast, operated with ropes (See Figure 4). A 4m long, 10 cm thick artefact, interpreted as a possible mast, was documented near the Bracciano 1 boat find, though the interpretation is tentative (Mineo *et al.*, 2023, pp.38-39). We chose to replicate it based on our earlier experience from the Monoxylon expeditions (Tichý, 2019), which highlighted the possible importance of wind. It represented a return to testing a sail, which had been planned for the first crossing of the Aegean Sea (See Figure 1). At that time, we could not proceed because of our lack of knowledge of weather/ wind conditions. The sail was used minimally in 2019 (Monoxylon III) because of the chosen route and the time of the voyage. That time, we chose a windless part of the year (Tichý, 2020). In 2023, the situation was different. Some of the stages were chosen deliberately to test wind power (See Figure 3) despite the lack of archaeological evidence of sail used in such an early period.

The sail was a simple, loosely woven rectangle, which partially let wind through. That, to a certain extent, mitigated the pressure on the vessel during wind gusts. The sail was usable only for following and following-side winds. Thanks to the experience of the crew, even a very weak wind could be used, with the sail being positioned nearly parallel to the boat. The sail was fastened between two sailyards. It was possible to pull the top sailyard to the top of the mast. The guiding ropes were attached to the ends of the yards. This simple system used five ropes which were attachable to the hull of the vessel thanks to wooden objects with holes, like the 'T artefacts' found near the boats at the Bracciano site. Their replicas were tested in 2019. In 2023, the ropes were attached in a different, simple way. We do not consider the 'T artefacts' necessary for fastening ropes. Their function cannot be either confirmed or denied by the experiment. The sail could have been very quickly lowered by lowering the top sailyard and simultaneously rolling the sail onto the bottom sailyard. The rolled sail was then fastened vertically to the mast.

As a result of our trials, we can say that a simple sail could successfully support a vessel in the conditions around the islands of the Aegean Sea (See Figure 3). It was most noticeable during stages two and three, but also in the second half of stage 15 (See Figure 13a). The use of the sail speeded the vessel up and shortened the time spent at sea, even if used only for parts of the stages. This way, it reduced the influence of a quick weather change on a safe landing. Support of the sail managed to increase the speed of the vessel up to 7 km/hour. The average speed of all stretches thus reached 5.4 km/hour, that is over 1km faster than in 2019, when the sea conditions were much calmer, and we alternated two crews.

The fundamental tool for navigating the replica vessel was a long steering paddle (See Figure 5, 11b). In high following waves (up to 1.5m) the steering paddle sometimes did not reach below the sea surface and the vessel became uncontrollable. Because of the total weight of the vessel (2.7 tonnes when dry, at sea up to 3.3 tonnes) attempts to control the boat with just paddles were not effective. It is, therefore, a question if artefact 12005 found between boats 2 and 4 at Bracciano (Caruso Fermé, *et al.*, 2023) could have been used as a helm or if it is just an alternative fastening of the paddle leaf. Equally, it could have possibly served to steer while navigating the lake.

Crew

The modern experimenter is the weak link in any archaeological experiment. They are part of a modern society, and their experiences and skills influence the experiment (Dvořáková, 2024). On the top, we do not know anything about physical performance in prehistory. While we justifiably presume that it was better than of a modern human, it does not apply on a general level. I would like to correct the information that the crew of Monoxylon III (2019) was inexperienced (Mineo, *et al.*, 2021; Mineo, *et al.*, 2023; Gibaja, *et al.*, 2024). That information came from unofficial internet sources. In reality, part of each crew were members of the previous expeditions. Even among the 21-member crew of 2023 there were five people who took part in all four expeditions and another eight took part in one or two of the previous expeditions. It was important that experience and physical condition were not the only measures we could arrange to ensure the quality of a nautical experiment.

There are other factors concerning the crew. For example, in 1995, a third of the crew switched while at sea. In 1998, during the longest expedition (800km), three crews switched. In 2019, two crews switched. In 2023, there was only one crew.

The positions of those who manipulate the sail are important as these are specialised activities. There were two helmspersons who shared the effort because of the great strain of sailing in waves. In 2023, the number of crew members rose to 21 (until then, at most 11 persons), which required one crew. A failure of a paddler is when, because of tiredness, they decrease the frequency of paddling, given by seat one, or they stop paddling and lower the vessel's performance. One of the risks we faced in 2023 was the hot weather, with temperatures approaching 40°C. When the surface was calm, the crew needed to bathe (See Figure 5). Even this time was used for taking measurements (possible influence of the surface currents), but it was necessary to deduct it from the time of overall performance of the vessel during the given stage.

Despite the 2023 crew containing 20 paddlers, some required rest after only a few hours of paddling. From the total number of ten benches, three benches were rested in intervals of 15 minutes. The last, tenth bench rested on their own. The most demanding stage lasted 11 hours, there the rest was necessary. At the dangerous moments of sailing there was no resting. All these changes to the performance were recorded as factors influencing the measured results.

Vessel cargo

The point of any sailing is the transport of cargo. With an average weight of 70kg per person, the load bearing capacity of the 2023 vessel was at least 1500kg. Thanks to the earlier described system of resting shifts, the vessel performance recorded with only 14 active paddlers was similar to that of a full crew. The cargo was, therefore, estimated as the weight of 6 persons of 70kg average, that is at most 400kg. The weight of the passive cargo could also have been deduced as load bearing capacity above the weight of the 20 active paddlers. It is possible to imagine that the boat load could be increased by another 400kg, if we take into consideration the difference of the weight of the boat in dry condition (2700kg) and long term wet condition (approximately 3300kg). So the vessel of type Bracciano 1 could carry, apart from the crew of 20, an extra load of at least 400kg.

Stability, speed and resistance in waves

If we want to evaluate the capability of Bracciano 1 for sea navigation, then the stability and speed of the vessel and its possibilities in navigating waves are important parameters.

The stability of the replica was positively influenced by its flat bottom. The first impression was not unambiguous, especially when the paddlers were changing sides and the vessel was swaying in a way that could not be compensated for by the helmsman. The vessel was further rocked by the movement of the sea when the flat bottom kept its position parallel to the sea surface. In a protected calm bay at Levitha Island, we attempted to turn the vessel over. We managed it only after rocking the boat from side to side repeatedly to gain momentum and then the whole crew leaning over the same side.

Another parameter is speed. It is influenced by a number of factors, which include the number of paddlers, use of a sail, strength and direction of the wind, height and direction of waves. The speed could also be influenced by the proximity of the land, which does not allow, even in strong winds, for the development of large waves. On the basis of the listed influencing factors, it is possible to create a scale of conditions from the highest speed to the slowest (1 being the highest possible speed),

1. speed with a following wind, under sail, paddling, sheltered by coastline
2. speed provided by 20 paddlers, sheltered by coastline
3. speed provided by 14 of the 20 paddlers, sheltered by coastline
4. speed on the open sea, mild wind, 20 paddlers
5. speed in head-side wind, open sea
6. speed in high, following, waves, open sea
7. speed in long, high, side waves, open sea
8. speed in short, high, side waves, open sea
9. low speed because of heat, length of the stage or loss of motivation

The influence of waves and wind were identified as fundamental factors influencing performance of a simple vessel during the Monoxylon expeditions (Tichý, 2016; 2020). A powered boat has some advantages in comparison to a passive vessel, at least in some situations (for example, sailing in long side waves). Below, we describe concrete examples of conditions that we experienced during the Monoxylon IV Expedition in 2023, their position and number of the route are shown in Figure 3. It shows the high variability of natural conditions during the experimental voyage. We therefore take it as suitable to define types of navigation under the influence of wind and waves independently of human influence (the listed types regularly repeated during the previous expeditions with minor differences). Despite that, the human influence shows in types 8 and 9, which did not take place during the 2023 voyage, mostly because during such conditions, the vessel did not launch, or such conditions were avoided on route.

Type 1 short side waves (Figure 6b): danger of occasional flooding of the boat, but the boat does not lose speed.

Type 2 high and long side waves (Figure 7b): they allow for better performance than head waves. They even allow for the vessel to 'surf' them - to slide along them with deliberate steering of the vessel.

Type 3 calm surface and strong wind while being sheltered by the land (Figure 8b): The land prevents the strong wind from starting waves. In a suitable wind, it is possible to use it for sailing.

Type 4 head side waves (Figure 9b) considerably slow the vessel but less than head waves.

Type 5 following high waves (Figure 10b) create an impression that they are helping the boat, but in reality, they can make the boat difficult to steer.

Type 6 head side strong wind (Figure 11b) causes short waves that flood the vessel and pull the vessel away from its chosen direction.

Type 7 side and following wind on the open sea (Figure 12b). If the wind is not too strong, the waves do not flood the vessel, and if it is in a suitable direction, it can be used for sailing.

Type 8 calm surface and windless conditions (Figure 13). The calm surface creates an impression of suitable conditions, but the crew has to work hard to power the boat without any support while at risk from heat.

Type 9 following strong wind in short waves. It is necessary to lower the sail, as there is a risk of the vessel flooding.

Type 10 headwind and head waves (or just one of them). It was tested for a short while during an out-of-control turn of the vessel in the opposite direction (Figure 10a). Movement forward was impossible, and the risk of flooding was high.

Conclusion

The aim of the nautical experiment was to evaluate the characteristics of the replica of Boat 1 from the Early Neolithic site at Bracciano lake (referred to as Bracciano 1 in this text) as a see going vessel. The experimental boat corresponded with the original as much as possible given current knowledge. We chose the time to test the boat in changeable conditions. The route was established to follow a possible route of obsidian transport in the Early Neolithic. To create conditions as close as possible, we travelled with only one set of crew and used the time when the weather was unsuitable for rest.

One of the surprises was the increase in speed in comparison to our earlier expeditions. It seems that the extra length allowed for faster travel in waves. The speed while paddling under normal conditions reached up to 5.5km/hour. Sail use increased the vessel's speed up to 7 km/hour. This is important for the presumed transport of animals in Early Neolithic vessels (Broodbank and Strasser, 1991; Vigne, *et al.*, 2013; Bar-Yosef Mayer, *et al.*, 2015). It also supports the chance of safe arrival in the changeable weather conditions of the Aegean Sea. Evaluating the load bearing of the vessel is also of fundamental importance. Apart from the active crew, there is the possibility of other cargo - both live (passengers, animals) and inanimate (for example, obsidian). The weight of such additional cargo for our replica was estimated at 400kg.

As part of evaluating the conditions of the Expedition Monoxylon IV, it is necessary to mention the demanding environmental conditions caused by strong winds and high waves of up to 1.5m. On occasions the boat was at the limit of its capabilities. This evaluation is not based on the crew's feelings but on the risk of the boat being flooded. Bailing during the demanding conditions was a necessity and it kept the boat from sinking. On the other hand, our concern that the boat might overturn because of its flat bottom proved unfounded asthe boat was stable in the waves. In a sheltered bay of the Levitha Island we attempted tocapsize the boat deliberately. It took considerable effort and was much more difficult than we imagined. Among the important risk factors was the loss of steering ability, which happened twice during stage 3 while navigating in high following waves. The vessel turned in the opposite direction and, for a short time, was out of control. The reason for this loss of control was the height of the waves, which meant the steering paddle did not reach into the water and so stopped functioning.

During the the 15 stages in June and July 2023 of the voyage, the experimental vessel traversed more than 500km long route across the Aegean Sea in demanding weather conditions. Based on the results of the nautical experiment, sailing a Bracciano 1 type boat on the open sea seems possible.

Keywords boat / ship
experimental archaeology

Country Greece
Turkey

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Gallery Image

FIG 1. THE FIRST LOGBOAT REPLICA IN 1995. PHOTO BY EXPEDITION MONOXYLON ARCHIVE.

FIG 2A. THE SECOND LOGBOAT REPLICA IN 1988. PHOTO BY EXPEDITION MONOXYLON ARCHIVE.

FIG 2B. THE ADJUSTED SECOND REPLICA IN 1998. PHOTO BY EXPEDITION MONOXYLON ARCHIVE.

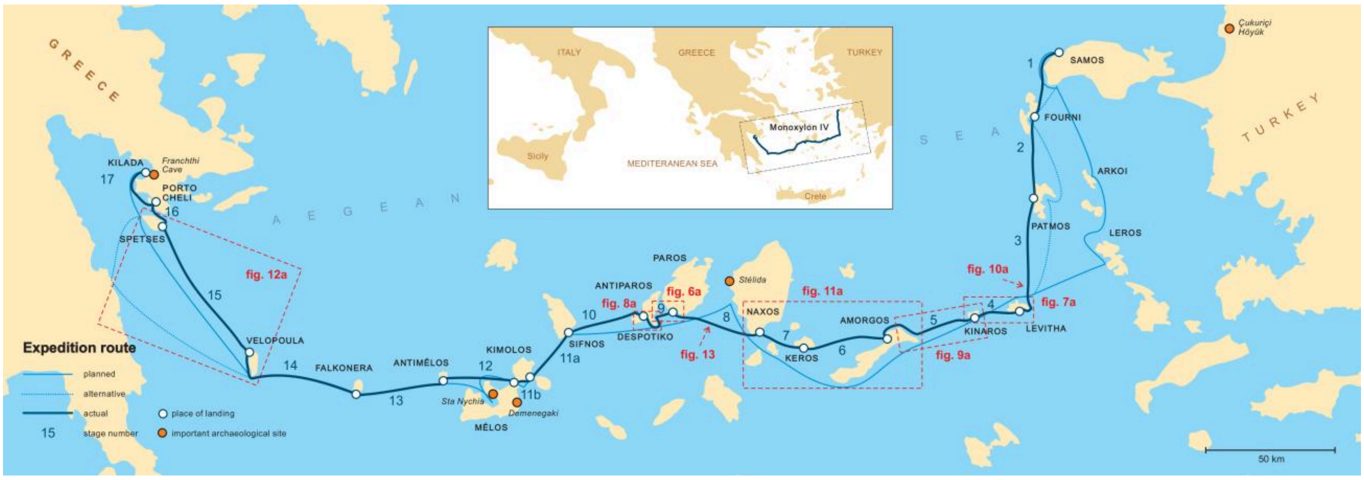

FIG 3. THE ROUTE OF MONOXYLON 4 EXPEDITION WITH MARKED STAGES AND LOCATION OF WAVE TYPES ALONG THE ROUTE. MAP BY ONDŘEJ ŠTULC.

FIG 4. THE SIMPLE SAIL IN 2023. PHOTO BY EXPEDITION MONOXYLON ARCHIVE.

FIG 5. MEASURING OF DRIFTING OF THE BOAT AWAY FROM ITS DIRECTION WHEN UNPOWERED. PHOTO BY EXPEDITION MONOXYLON ARCHIVE.

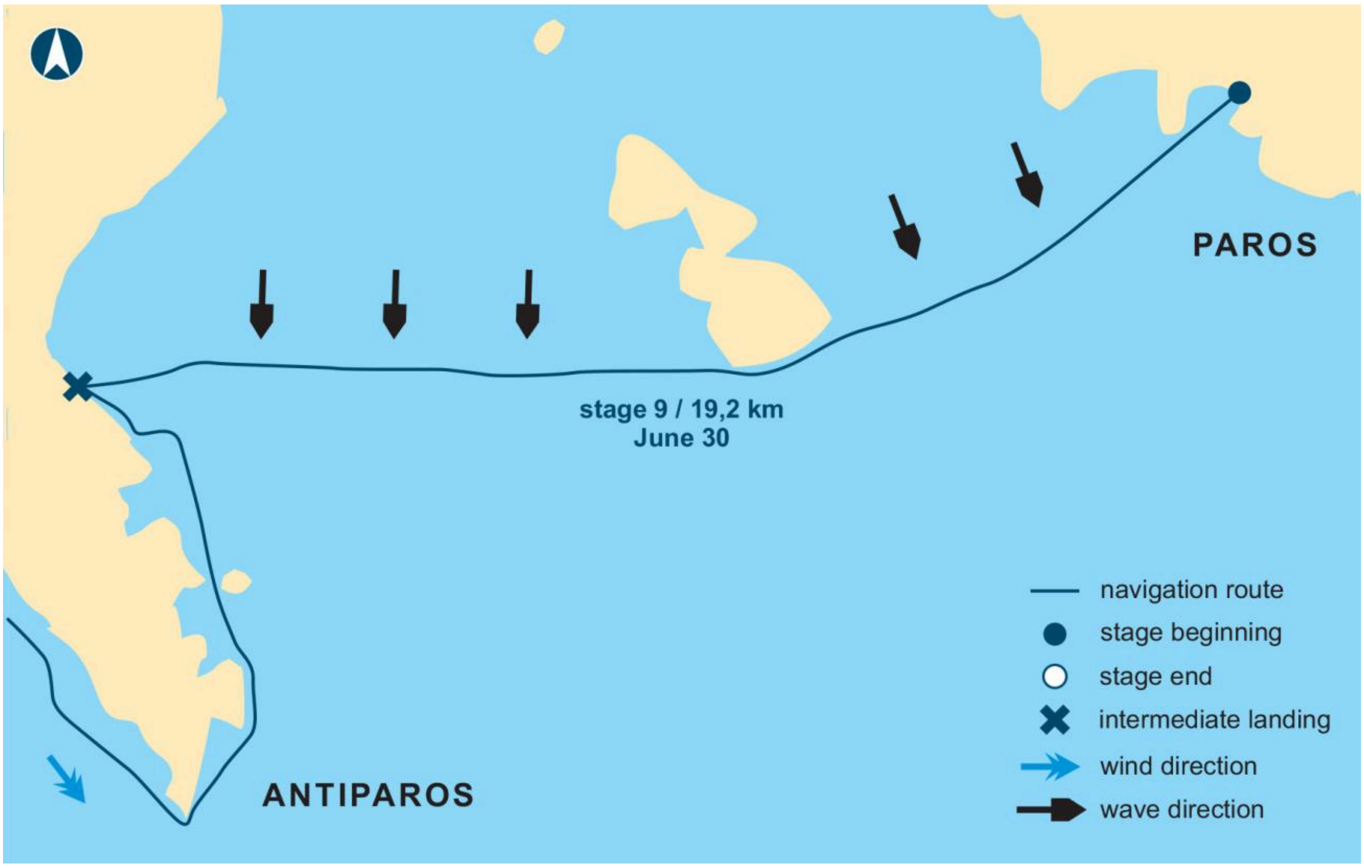

FIG 6A. PLACES WHERE EXPEDITION ENCOUNTERED CONDITIONS TYPE 1 (SEE FIGURE 6B). MAP BY ONDŘEJ ŠTULC.

FIG 6B. TYPE 1 SHORT SIDE WAVES: THERE IS A DANGER OF OCCASIONAL FLOODING OF THE BOAT BUT THE VESSEL DOES NOT LOSE SPEED. PHOTO BY EXPEDITION MONOXYLON ARCHIVE.

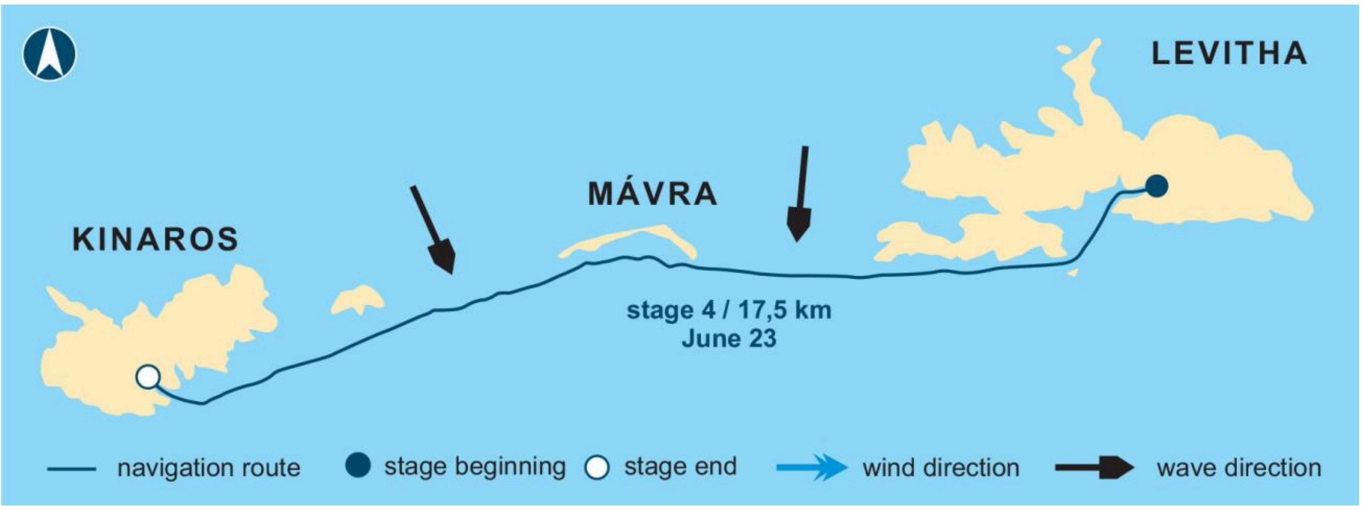

FIG 7A. PLACES WHERE EXPEDITION ENCOUNTERED CONDITIONS TYPE 2 (SEE FIGURE 7B). MAP BY ONDŘEJ ŠTULC.

FIG 7B. TYPE 2 HIGH AND LONG SIDE WAVES: THEY ALLOW FOR EASIER NAVIGATION THAN HEADWAVES. IT IS POSSIBLE TO DELIBERATELY 'SURF' THE WAVES. PHOTO BY EXPEDITION MONOXYLON ARCHIVE.

FIG 8A. PLACES WHERE EXPEDITION ENCOUNTERED CONDITIONS TYPE3 (SEE FIGURE 8B). MAP BY ONDŘEJ ŠTULC.

FIG 8B. TYPE 3 CALM SURFACE AND STRONG WIND IN THE LEE OF LANDMASS, THE LAND IMPEDES CREATION OF WAVES, WITH SUITABLE DIRECTION THE WIND CAN BE USED FOR SAILING. PHOTO BY EXPEDITION MONOXYLON ARCHIVE.

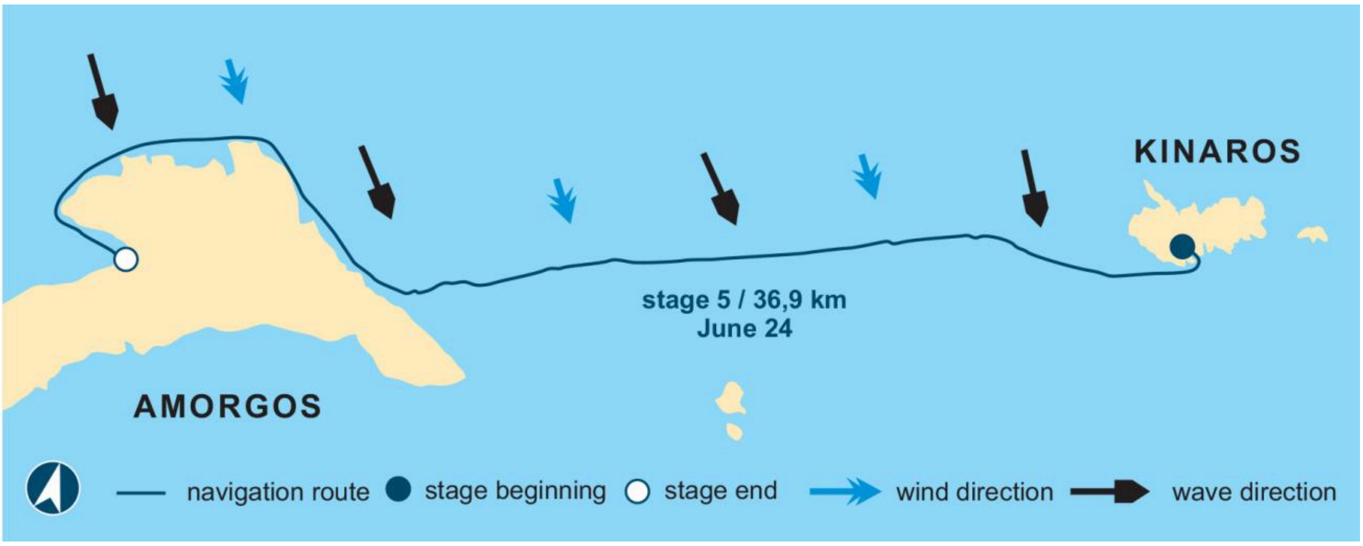

FIG 9A. PLACES WHERE EXPEDITION ENCOUNTERED CONDITIONS TYPE 4 (SEE FIGURE 9B). MAP BY ONDŘEJ ŠTULC.

FIG 9B. TYPE 4 SIDE-HEAD WAVES: THEY CONSIDERABLE SLOW THE VESSEL BUT LESS THAN HEADWAVES. PHOTO BY EXPEDITION MONOXYLON ARCHIVE.

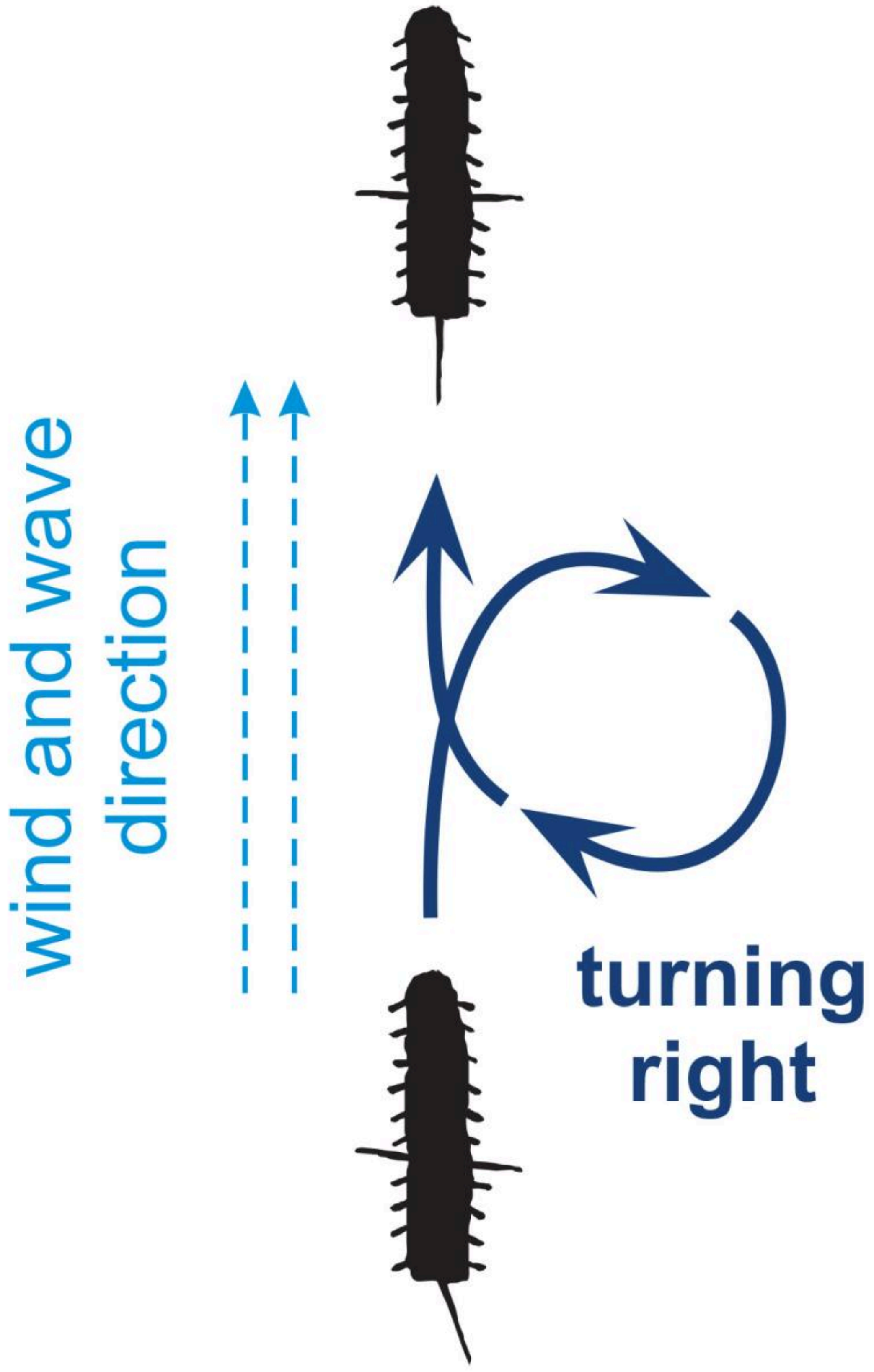

FIG 10A. TYPE 10 HEADWIND AND HEADWAVES (OR ONE OF THEM), ATTEMPTED FOR A SHORT TIME DURING UNCONTROLLED TURN OF THE VESSEL INTO THE OPPOSITE DIRECTION, FORWARD MOVEMENT IS NOT POSSIBLE, THE RISK OF FLOODING IS HIGH. IMAGE BY EXPEDITION MONOXYLON ARCHIVE.

FIG 10B. TYPE 5 BACK HIGH WAVES: THEY CREATE AN IMPRESSION THAT THEY PROPEL THE VESSEL BUT THEY CAN MAKE THE VESSEL UNCONTROLLABLE. PHOTO BY EXPEDITION MONOXYLON ARCHIVE.

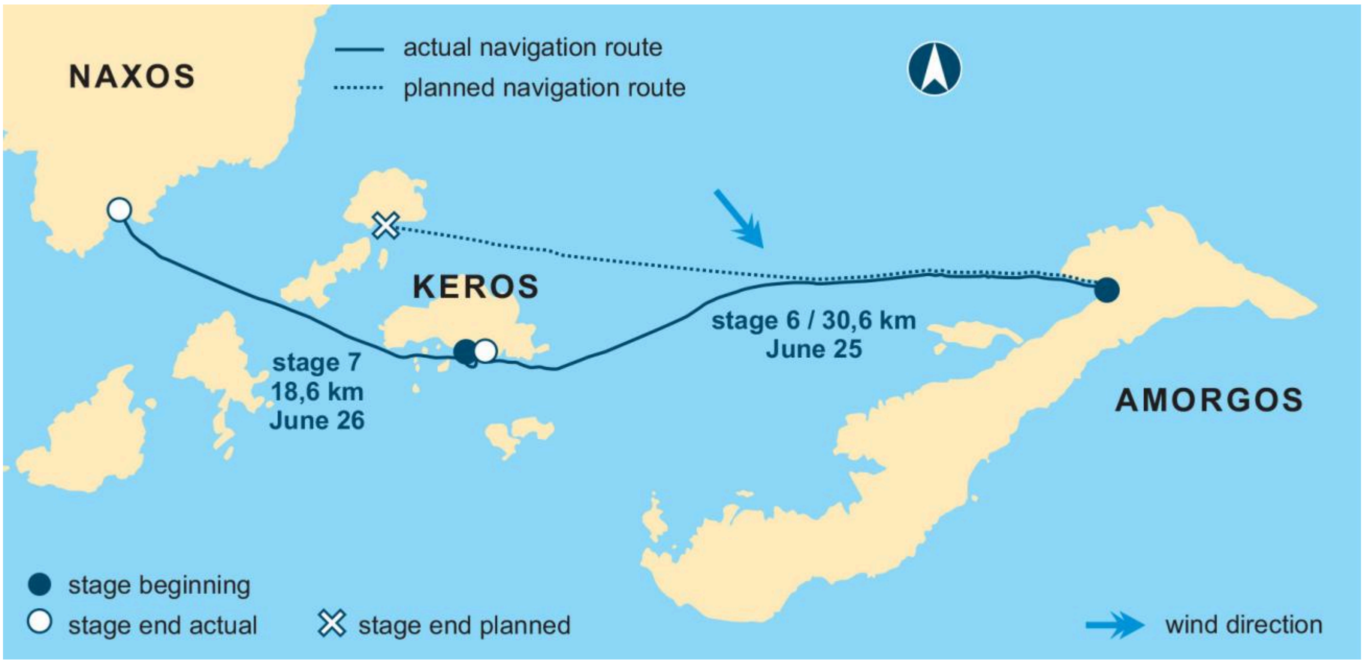

FIG 11A. PLACES WHERE EXPEDITION ENCOUNTERED CONDITIONS TYPE 6 (SEE FIGURE 11B). MAP BY ONDŘEJ ŠTULC.

FIG 11B. TYPE 6 HEADSIDE STRONG WIND: THE WIND CAUSES SHORT WAVES WHICH FLOOD THE VESSEL AND PUSHES THE VESSEL AWAY FROM ITS DIRECTION. PHOTO BY EXPEDITION MONOXYLON ARCHIVE.

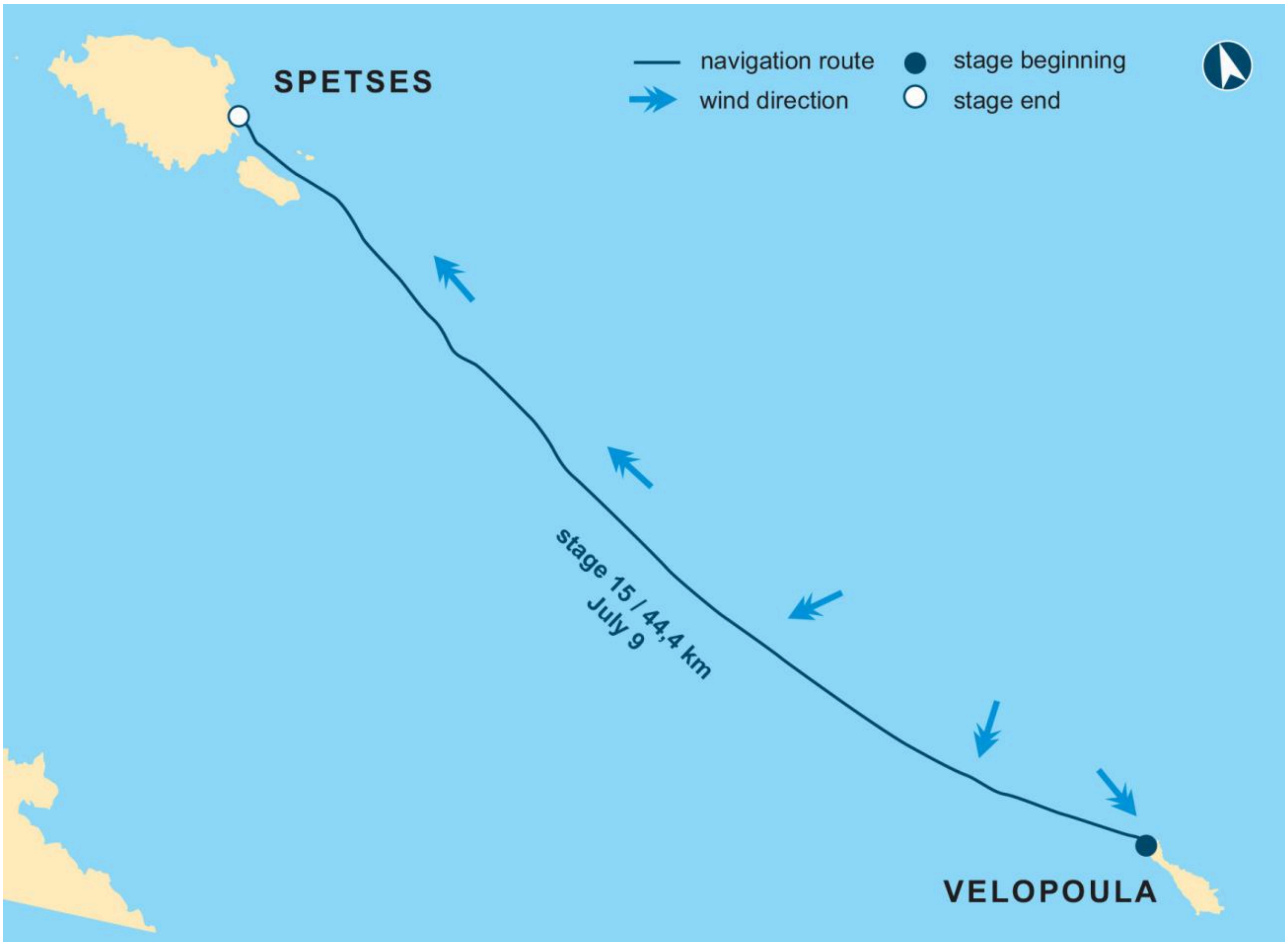

FIG 12A. PLACES WHERE EXPEDITION ENCOUNTERED CONDITIONS TYPE 7 (SEE FIGURE 12B). MAP BY ONDŘEJ ŠTULC.

FIG 12B. TYPE 7 SIDE AND FOLLOWING WIND ON OPEN SEA: IF THE WIND IS NOT TOO STRONG, THE WAVES DO NOT FLOOD THE VESSEL AND THE WIND MIGHT BE USED FOR SAILING. PHOTO BY EXPEDITION MONOXYLON ARCHIVE.

FIG 13. TYPE 8 CALM SURFACE AND WINDLESS CONDITIONS: THE CALM SURFACE GIVES AN IMPRESSION OF FAVOURABLE CONDITIONS BUT THE CREW HAS TO WORK HARD, THERE IS A HIGH RISK OF HEAT EXHAUSTION. PHOTO BY EXPEDITION MONOXYLON ARCHIVE.