The fate of human remains in a maritime context and feasibility for forensic humanitarian action to assist in their recovery and identification

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\textbf{A B S T R A C T}

The number of annual maritime fatalities reported in the Mediterranean has more than doubled in the last two years, a phenomenon closely linked to the increase of migrants attempting to reach Europe via the Mediterranean. The majority of victims reportedly never gets recovered, which in part relates to the fact that the mechanisms and interaction of factors affecting marine taphonomy are still largely not understood. These factors include intrinsic factors such as whether the individual was alive or dead at the time of submergence, the individual’s stature and clothing, as well as extrinsic factors such including ambient temperature, currents, water depth, salinity and oxygen levels. This paper provides a compilation of the current literature on factors influencing marine taphonomy, recovery and identification procedures for submerged remains, and discusses the implications for the retrieval and identification of maritime mass fatalities as part of the humanitarian response, specifically humanitarian forensic action, to the consequences of the current migration phenomenon.

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1. Introduction

Recent years have seen an unprecedented humanitarian tragedy due to a loss of human life at sea in the Mediterranean. This is particularly linked to the upsurge of migration, including through maritime routes such as those crossing the Mediterranean; whilst the sea route to the EU is not a new one, the number of individuals commencing on this journey is exponentially growing, as is the death toll attending this increase, as the vessels utilized in the crossings are frequently of low quality and filled way above their capacity [1]. Between 1988 and 2013 a reported 14,309 people died in an attempt to cross the Mediterranean [2], in 2014 and 2015 combined, 7191 people were reported to have lost their lives; the actual number is likely even higher. 2016 alone has seen 4913 casualties [3]. Many victims never get recovered or identified. However in an unprecedented operation, in June 2016 the Italian Navy recovered a sunken fishing boat believed to have held more than 800 migrants when it capsized in April 2015, and identification efforts are underway at the time of writing.

Whilst the majority of maritime fatalities are related to migration, other recent prominent incidents resulting in a large number of individuals finding death in marine bodies of water include the crash of Yemenia flight 626 in 2009, the sinking of the MS Spice Islander I off the coast of Zanzibar killing up to 1500 people in 2011, the crash of Air France flight 447 in 2009 with 228 fatalities, the 2014 sinking of the Sewol ferry in South Korea, causing the death of 304 individuals, Egypt Air flight 804 killing 66 when crashing into the Mediterranean in early 2016 as well as most likely Malaysian Airlines flight 370 which vanished off the radars over the Indian Ocean with 239 people on board in 2014. The increasing number of mass fatalities in the maritime context poses particular challenges for the recovery and identification of the dead.

Every human being has the right not to lose his or her identity after death [4], and the necessity to retrieve and identify the deceased for humanitarian, judicial and administrative reasons, is not only universally recognized, but also perpetuated in domestic and international law, such as the 1949 Geneva Conventions [5], and their 1977 Additional Protocols [6]. Under International Humanitarian Law (IHL), the dead from armed conflict are a distinct category of victim with the right to having their dignity protected; though the matter of management of the dead is not yet specifically addressed in the evolving body of International Disaster Response Law (IDRL), with the exception of situations

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in which death was caused by negligence of a State, the adequate management and identification of disaster victims is equally important [7,8]. Nonetheless, for many individuals who lose their life at sea, this does not materialize for a variety of reasons [1].

Despite their relevance in the recovery and identification efforts of human remains from the sea, the mechanisms and factors affecting marine taphonomy are still largely not understood, as research in this area to date has been scarce. There are multiple factors affecting the fate of human remains in the marine context, including intrinsic factors such as whether the individual was alive or deceased at the time of submergence, stature and clothing, as well as extrinsic factors including ambient temperature, currents, water depth, salinity and oxygen levels. Much of the current body of knowledge concerning marine taphonomy is derived from case observations and some experimentally conducted research off the coast of British Columbia.

It is the aim of this paper to provide a compilation of the current body of knowledge relating to the fate of human remains in a maritime context. This includes processes of marine taphonomy, recovery and identification procedures for submerged remains, and the implications for the retrieval and identification of maritime related mass fatalities, in particular in light of the current migration phenomenon and humanitarian efforts, particularly forensic humanitarian action, to properly manage and identify the dead from these events.

The following sections will discourse upon the factors playing a role in the successful retrieval and identification of human remains, such as water drift, the intrinsic and extrinsic factors influencing the decomposition rate and pattern, as well as technical approaches to the detection and recovery of human remains from a maritime environment. Finally, identification methods will be discussed.

2. Drift

There is a number of factors influencing a body’s horizontal and vertical displacement in water after drowning [9]. Vertical movement is dependent on the body’s gravity and the relationship of its density to the density of the water; the average density of males and females is 0.98 and 0.97 g/cm³ respectively, the density of salt water is 1.024 g/cm³ [10]. This results in the fact that less dense human bodies have a tendency to float, however even small variations have a severe influence on buoyancy [11,12]. This, in turn has a direct impact on horizontal displacement. Particularly in cases of drowning an increase in body specific gravity and subsequent decrease in buoyancy due to increased lung weight through water inhalation or increased stomach weight through water ingestion, leads to a sinking of the body [11]. Once sinking commences, the hydrostatic pressure, which increases by 1 atm. for every 10 m depth, compresses gas containing cavities in the body, causing it to sink to the bottom. The settling of remains on the bottom of a body of water is dependent on factors such as the water currents and the type of substrate [10]. The increased frictional forces at the bottom of maritime environments in combination with the decreased velocity of the water current at greater depths result in the drag forces frequently not being able to overcome gravitational forces and less horizontal body displacement to occur [11]. Significant horizontal displacement therefore only occurs after the body resurfaces if it is not immediately recovered. In cases in which the individual entered the water already dead, died of reasons other than drowning or was wearing a flotation device, it is possible for it to not sink at all [13] and drift of up to 380 km in 60 h [14].

Sunken bodies resurface once they enter the bloating stage of decomposition, the putrefactive gases decreasing the body specific gravity and increasing buoyancy. The exception to this are bodies which are trapped in a structure at the bottom or if they have sunk to depths greater than about 60 m [13,15]. The main factor affecting the rate of decomposition is the ambient temperature, the process thus slowing down in lower water temperatures. Another factor influencing decomposition rate is hydrostatic pressure, with low hydrostatic pressure being more conducive to decomposition. It is therefore not uncommon for sunken bodies to resurface in coastal regions during low tide, as the decrease in water column lowers the hydrostatic pressure on the body [11].

Oceanic currents and particularly drift currents, which are dependent on atmospheric changes, can be highly variable, however there are several numerical oceanographic forecast models which can be accessed, such as the Mediterranean Forecast System Pilot Project (MFSPP), the Princeton Ocean Model (POM) [16] or the US Navy’s Naval Oceanographic Office (NAVO) which runs the Shallow Water Analysis and Forecast System (SWAFS), operational models for marginal seas around the world [17–20].

Predicting body displacement in marine environments is highly complex and the collaboration of forensic and operational oceanographic expertise, such as accumulated by the agencies mentioned above, is paramount for such investigations.

3. Decomposition and taphonomy

The process of decomposition in water generally progresses slower than on land, which is due to the cooler temperatures as well as the absence of necrophagous insects. When comparing the differing aqueous environments, salt water decomposition proceeds at an even further decelerated rate than that in fresh water. This can be attributed to the fact that in the latter water is absorbed into the circulatory system, causing organs to swell and rupture, whereas in the former, fluids are drawn out of the blood and the high salinity slow bacterial activity [10]. The decomposition of remains in the marine context also heavily depends on many other factors, including whether the remains sink or float. In floating remains disarticulation of the appendages through current and wave action weakening the soft tissue connection of the joints is a common factor [21]. The generally observed sequence of disarticulation occurs at major joints, from distal to proximal; on the upper limbs the first to disarticulate are the wrist joints, the elbow and the shoulder joints. On the lower limbs loss of the feet at the ankle joint is followed by the knee joint. The mandible disarticulates around the same time as the hands, and the cranium is lost parallel to disarticulation of the forearms [21]. This pattern, however can be altered through the presence of clothing, which may preserve the soft tissue and inhibit disarticulation (Figs. 1 and 2).

![Fig. 1. Differential decomposition after 70 days of submersion, due to the body being protected by clothing; note disarticulation of the mandible.](image-url)
Researchers at Simon Fraser University have monitored the decomposition process at various depths (7.6 m, 15.2 m, 94–99 m and 300 m) experimentally in the Pacific Ocean off the Coast of British Columbia, by utilizing pigs as human proxy [13,22,23]. At the shallow depths of 7.6 m and 15.2 m the remains, 50% of the carcasses were still floating despite having been deceased prior to their placement in the water. The remains which had sunk showed more severe scavenging and skeletonization than those floating [23]. The remains deployed at depths of 94–99 m were found to sink immediately. After 14 days the carcasses were partially skeletonized due to scavenger activity (mainly lysianassid amphipods); all soft tissue and most of the cartilage was removed by day 42. All tissue loss at these depths was entirely due to animal feeding and not related to decomposition [13]. Anderson [13] further noted that in instances in which the oxygen levels dropped to hypoxic levels of below 2.0 mL/L, virtually no scavenger activity took place, leaving the remains intact. Remains placed at a depth of 300 m immediately attracted lysianassid amphipods, which first consume the internal organs followed by the skin, and completely skeletonized the remains within 4 days. It was noted that after skeletonization bones were rapidly covered by silt, with black discolorations forming both on the skeletal elements and the surrounding silt, which was observed from day 23 post deposition [22].

Dumser and Türkay [24] reported the location and recovery of skeletal human remains at a depth of 580 m, 89 days after a mid-air jet aircraft collision off the Namibian coast. The skeletal elements were in the immediate vicinity of the plane wreckage and although disarticulated, still in anatomical order and partially clothed. In another incident involving a helicopter accident over the Mediterranean Sea, partially decomposed and fully clothed remains were recovered at a depth of 540 m after 34 days. It is to be noted that this incident occurred in an ecological environment devoid of the highly scavenging lysianassids [24].

Following the crash of Yemenia Flight 626 into the Indian Ocean in 2009, which cost the lives of 152 individuals (leaving one sole survivor), 24 bodies were washed ashore 300 nautical miles away, 7 days after the crash and 70 were recovered from a depth of 1280 m after 70 days of submergence [25]. The remains displayed a highly differential decomposition, with parts of the remains still fully fleshed, while others, particularly in the cervico-cephalic region being skeletonized. Over 60% of the victims recovered from the sea bed exhibited circular lesions attributed to scavenging by cookiecutter sharks (Isistius), while victims who were found drifting on the surface displayed large classical shark bites. (Examples of shark and Isistius scavenging can be seen in Figs. 3 and 4).

It has been possible to successfully recover and identify 154 of the 228 victims of the 2009 Air France Flight 447 crash into the Atlantic Ocean. Fifty were floating on the ocean surface in the immediate aftermath of the crash, 104 were recovered from a depth of 4000 m after 21 months of submergence [26]. Differential preservation of the remains was observed, with remains in contact with the sediment having been mostly skeletonized and remains suspended in the debris still having been virtually intact. A remarkable protection of soft tissue through clothing was observed [26]. Predation occurred by amphipods as well as squat lobsters (Galatheae), which were observed to gnaw on bone epiphyses and leaving bone lesions on cancellous bone as well as the external table of the crania. Examples of Galatheae scavenging can be seen in Figs. 5–6. There was no predation from Isistia or larger sharks. Observed polytrauma of the remains was associated with the crash. Skin and bones in direct contact with the sediment exhibited black discoloration.

Decomposition patterns are further altered in instances in which the remains are in an enclosed environment not permitting access to scavengers, in which cases adipocere formation is often observed. Adipocere is a waxy byproduct of decomposition which is formed by the hydrolysis and hydrogenation of tissue fat, which typically forms in anaerobic, moist environments, and once formed has been observed to remain unchanged for at least 150 years, inhibiting skeletonization [27]. Depending on factors such as the type of fatty acids, the temperature, immersion depth and clothing, adipocere can either be hard and crumbly, or soft and paste like
Adipocere formation has been reported as early as 38 days post submergence in remains recovered from a ship wreck in the East China Sea from a depth of 85 m [27]. In the case of the Air France Flight 447 crash, an incomplete saponification of fats, leading to easily dislodgeable white flaky deposits on the skin were observed, which is most likely due to the very high pressure of 400 bars [26].

4. Detection and recovery

In deep sea environments, typically remotely operated vehicles (ROV) equipped with a colour video camera are deployed [24] (Fig. 9). Ideally the video images should be monitored by forensic personnel, as was the case for the recovery of the Air France Flight 447 recovery. In some instances sonar exploration of the sea bed can be deployed prior to the sending of an ROV.

Recovery dives need to be carefully planned and diver’s safety is of paramount importance. For handling cadavers in underwater recovery operations specific training is required, as recognizing human tissue in different states of preservation and under different circumstances such as poor visibility and/or confined spaces requires specific knowledge and experience [28,29]. The psychological impact of such recoveries on divers also has to be taken into consideration. During the recovery of the victims of the
Air France Flight 447 crash, a psychiatrist and a psychologist were on board at all times to offer support to the crew.

In order to facilitate optimal prerequisites for identification, remains need to be bagged in a consistent manner and the area surrounding the remains need to be carefully examined and documented, including the recovery depth. In order to allow for a re-visiting of the scene if necessary, a marker should be placed [28]. Remains should be bagged under water in order to minimize the loss of physical evidence [28]; special water recovery bags made out of vinyl coated polyester mesh are available, which allow for easier recovery while submerged and quick drainage once removed from water. Once on deck bodies can be transferred into conventional, leak proof bags.

In deep sea recoveries the bagging of remains under water is not feasible. In these instances ROVs equipped with robotic arms have been deployed in past operations. Using visual control, intact remains are gripped by the robotic arm at belt level, by the lower limbs or shoulder and placed into a metal collection basket (Figs. 10–12). Individual body fragments can be picked up and placed into the collection basket separately. In case of the AF 447 Flight, the basket was towed to the surface by a 4000 m long cable with an ascent time of approximately 3 h at a speed of 20 m/min [26].

Prior to recovery, a detailed description and positioning of the remains as well as associated items need to be recorded, and visibility permitting, photographs of the body and surroundings should be taken. All associated items need to be recorded, bagged and recovered. This is particularly crucial as, particularly in deep sea recoveries, bodies can undergo multiple changes during the ascent, including a stripping of clothing, loss of soft tissue, frequent joint disjunctions and detachment of appendages even at very slow ascent speeds. In addition the rapid increase in temperature accelerates decomposition [26].

Recovered remains need to be adequately stored aboard the vessel, requiring refrigeration until they can be transferred to land.

5. Identification

According to Winskog [28], around 60% of victims of maritime disasters are identified through odontology, this however being heavily dependent on the availability of ante-mortem records. In well preserved remains, deep muscle tissue can be sampled for DNA analysis, however even after removal of all soft tissues, DNA can be successfully extracted from submerged skeletal remains for decades [30], depending on the skeletal element. Goodwin et al. [31], were able to identify the remains of an individual who had been submerged in a Scottish Loch for 35 years based on his mtDNA profile and the amplification of nuclear DNA from a tibia. Fredericks et al. [32], who analyzed the remains of individuals which had been submerged in sea water for 2 and 4 years, observed the successful DNA amplification rate to be dependent on the skeletal element as well as the duration of submergence, and found a higher allelic dropout to occur in “low load” bearing bones. They noted the highest successful amplification rate from foot bones. It is paramount that the method of identification must not be decided before the body has been recovered from the water and have been examined by a forensic expert.

Additionally it has to be noted, that although visual identification and circumstantial identifiers such as tattoos or scars are undoubtedly useful, they are not always recognized as legally valid identifiers in every country. Under some jurisdictions, only primary identifiers (DNA, fingerprints and dental records) are accepted means of identification. If possible, remains should always be brought back to land to enable repatriation; however, in cases in which burial at sea is the only option, the remains need to be thoroughly documented and biological samples enabling future identification through primary identifiers need to be taken. For this purpose the use of FTA® paper or other biological storage cards should be considered, as these contain chemicals which break the cellular material, binding the DNA and thus allowing for the long term storage of biological samples at room temperature by protecting the DNA from microorganisms, UV light and oxidative damage [33].
6. Discussion and conclusion

Over the last two decades, knowledge regarding the effect of maritime environments on human remains has significantly increased, which contributes to the improvement of the effectiveness of humanitarian forensic action aimed at optimizing their recovery and identification.

Whether a body will decompose or be scavenged depends partly on its position in the water column. Remains in shallow water go through the stages of fresh, bloat, active decay and advanced decay and sometimes exhibit soft tissue for considerable periods of time, whereas cadavers in the deep sea have been found to exhibit differential preservation; they might not display any signs of decomposition, but rather be rapidly scavenged, or remain in a remarkable state of preservation for months and even years, if their position does not allow for scavenger access [13,22,23]. This knowledge is not only important for recovering divers to know what they are searching for, but also in order to manage next of kin expectations.

Deep sea searches are best carried out utilizing remotely operated vehicles equipped with a video camera, the footage being evaluated by someone with the necessary expertise. Remains need to be recovered in appropriate underwater body bags, and then be transferred to body bags allowing for potential subsequent analyses (such as CT scans). Provisions for the appropriate storage and cooling of remains after recovery need to be made, and a thorough analysis to determine identity, and in some instances cause of death, has to be carried out; this can take place aboard the vessel, provided a qualified professional is available, or transferred to an external medical examiner [26,28,29].

Although previous cases demonstrated that a recovery of victims even after prolonged periods of time and great depths is possible, the reality is that recovery efforts vastly depend on the circumstances, the profile of the case and the financial means and willingness of the responsible party. Most sunken vessels carrying undocumented migrants are never recovered. However, in an unprecedented operation, in June 2016 the Italian military has recovered a boat which sunk in April 2015 and which was believed to contain more than 800 deceased migrants from a depth of 370 m, which may set a positive impulse for future operations. Identification efforts are underway and will undoubtedly contribute to increasing the understanding of taphonomic factors affecting submerged remains. In the case of aviation disasters, determining the victim’s identities is made easier by the fact that they are closed incidents with fixed passenger manifests. Finding the next of kin for appropriate ante-mortem data is therefore a relatively straightforward task. With regards to sea fatalities resulting from migration, however, the fact that there is no record of the migrants departing on the journey across the Mediterranean, obtaining accurate statistics on related fatalities is challenging, and determining the identity of the majority of casualties is exceedingly difficult [1].

Nonetheless, locating and identifying the dead is a universally recognized value underpinned by domestic and international laws and humanitarian principles. Better insights into the marine taphonomical processes, as well as advances in technology are crucial to lay the foundation for improved forensic humanitarian action for the location, recovery and identification of individuals who lose their lives at sea, even from substantial depths and decades after death.

References