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ORIGINAL ARTICLE

# Time of immersion of bodies found in water in Northern Patagonia Argentina☆

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**Abstract**
*Introduction:* The estimation of the immersion time of bodies recovered from the water, through the evaluation of the cadaveric changes, allows inferring the time that they have remained in the water regardless of the cause of death. In the present study, the Daily Accumulation of Degrees (ADG) method is analyzed for the calculation of the immersion interval in bodies recovered from the water in 36 bodies with a known interval of permanence in the water.
*Material and methods:* A total of 161 bodies were recovered from the water between 2007 and 2022, in 41 cases there was data to be analyzed by the ADG method and 36 were suitable for analysis of the method when confronted with the known intervals of immersion of the bodies.
*Results:* The comparison of calculation by Daily Accumulation of Degrees versus Known Immersion Interval, of the sample of 36 cases, showed that the difference in days obtained is statistically significant ($p$ 0.48 > 0.005). In 16 cases (44.4%) there was an underestimation by the Daily Accumulation of Degrees method with respect to the time spent in the known water that differed by an average of 40%, and in 18 cases (50%) an overestimation of 41%. Based on the observation of the cadaveric changes, the month of the year and the water temperature, a table was made to estimate the Postmortal Interval of Immersion for watercourses in Northern Patagonia.
*Conclusion:* The method of Daily Accumulation of Degrees in bodies recovered from the water to estimate the immersion interval may give a false perception of accuracy due to the complexity of integrating all the changing factors that affect human decomposition in aquatic environments.


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**PALABRAS CLAVE**
Data;
Inmersión;
Agua;
Cadáveres

**Data de inmersión en cuerpos recuperados del agua en el norte de la Patagonia Argentina**

**Resumen**

*Introducción:* La estimación del tiempo de inmersión de cuerpos recuperados del agua, mediante la valoración de los cambios cadavéricos permiten inferir el tiempo que han permanecido en el agua independientemente de la causa de la muerte. En el presente estudio se analiza el método de Acumulación Diaria de Grados (ADG) para el cálculo de intervalo de inmersión en cuerpos recuperados del agua en 36 cuerpos con intervalo de permanencia en el agua conocido.

*Material y métodos:* Sobre un total de 161 cuerpos recuperados del agua entre 2007 y 2022, en 41 casos se contaban con datos para ser analizados mediante el método de ADG y 36 fueron aptos para realizar el análisis del método al confrontarlos con los intervalos conocidos de inmersión de los cuerpos.

*Resultados:* La comparación de cálculo por ADG versus Intervalo de Inmersión Conocido, de la muestra de 36 casos, resulto que la diferencia de cifras en días obtenidas es estadísticamente significativa (p 0,48 > 0,005). En 16 casos (44,4%) hubo una subestimación por el método de ADG con respecto al tiempo de permanencia en el agua conocido que difería en un promedio del 40%, y en 18 casos (50%) una sobre estimación del 41%. En base a la observación de los cambios cadavéricos, el mes del año y la temperatura del medio líquido, se confeccionó una tabla para la estimación del Intervalo Postmortal de Inmersión para cursos de agua de la Patagonia Norte

*Conclusión:* El método de Acumulación Diaria de Grados en cuerpos recuperados del agua para estimar el intervalo de inmersión, puede dar una falsa percepción de precisión debido a la complejidad de integrar todos los factores cambiantes que afectan la descomposición humana en ambientes acuáticos.



## Introduction

Estimating the time bodies recovered from water have been immersed is a relevant topic in forensic research; the cadaveric changes in these bodies make it possible to infer the length of time they have been immersed in water independently of the cause of death.

In 1977 Reh[1] reported a new method of determining the time of immersion of 395 bodies recovered from the River Rhine (Germany) after a known duration of immersion in the water, based on the cadaveric changes associated with the temperature of the water; this work was revised and updated by Doberentz and Madea in 2010; this updated suggested that increased water temperature leads to greater progression of putrefaction.[2]

These publications were milestones in forensic medicine, as they offered tools which make it possible to estimate the time bodies have been immersed when they are recovered from water.

Megyesi[3] introduced the concept of Accumulated Degree Days (ADD) to estimate the post-mortem time interval in bodies in soil. In 2010 Heaton[4] used the ADD concept to estimate the duration of post-mortem immersion based on the cadaveric changes in the head, trunk and limbs of 187 bodies recovered from water in the United Kingdom after known periods of time in water.

He thereby established a Total Aquatic Decomposition Score (TADS), with a maximum of 25 points. This categorizes different stages, from minimum changes to skeletisation.

As each TADS point corresponds to a figure which represents the ADD, if the average temperature of the liquid medium is known, it is possible to perform a regression calculation from the moment the body was recovered from the water until the possible date of disappearance.

The temperature of the water courses in Argentinian North Patagonia Argentina differs from the temperature of European rivers. The latter have a minimum temperature in winter of 5.7 °C and a summer maximum of 22.3 °C, with a temperate continental climate defined by a marked difference between a warm summer and a severe winter; on the contrary, the rivers in North Patagonia vary from 8.4 °C to 21.1 °C, respectively, and the climate is arid, dry and desert-like.

The aim of this study was to analyse the application of the ADD method according to the technique proposed by Heaton to determine the post-mortem interval of immersion (PMII) in bodies recovered from water. By analysing autopsy records and photographs of bodies recovered from the water after remaining in the same for a known period of time, an association was established between cadaveric changes, immersion time and the temperature of the water where the body was recovered. A standard table was then prepared which makes it possible to approximately calculate the date when a body had entered the water after it was recovered from a river, canal or lake in the Upper Valley of the River Negro in the north of Patagonia Argentina.

## Material and methods

### Location

A total of 161 bodies were recovered from water courses in Río Negro province in the north of Patagonia Argentina from 2007 to 2022.

The area of the study is located in the Patagonian plateau on the banks of the River Negro and both of the rivers which form it after they converge: Limay and Neuquén, their irrigation canals and a balancing lake (Fig. 1).

The climate is arid, desert-like and has wide thermal annual and daily variations, with moderate to strong winds in spring and summer, and frosts in the winter.[5,6] The historical data on the temperature in bodies of water are taken from the temperature records of the River Negro and its tributaries the Neuquén and Limay Rivers from 2007 to 2020. These originate in 10 sampling stations which take up to 3 measurements per month of the temperature over an area which covers 126 km within an area of 2,367 $km^2$, supplied by the *Autoridad Interjuridisccional de las Cuencas* (AIC) government body.

Monthly average temperatures were determined for this area of the said rivers and lakes (Fig. 1 and complementary material).

The average water temperatures in the area studied are 8.4 °C in winter and 21.2 °C in summer, and the rate of flow in the river Negro is 1,020 $m^3/s$ at a speed of from 2 to 2.5 m/s (7.2 to 9 km/h).[7] Areas which are always exposed to the sun alternate along the riverbank with other areas that are shadowed by vegetation which mainly grows along its northern bank. Recovered bodies had sometimes remained snagged in these vegetated areas.

### Material

The 161 adult bodies recovered from the water were all cases that had closed after judicial investigation. In 41 cases the autopsy report was available and showed the length of time the body had remained in the water. This was based on witness reports or reliable information about the date the body had entered the water, and there were also photographs taken during the autopsy or the removal of the body. These made it possible to determine the known post-mortem submersion interval (KPMSI).

### Methods

In this study the estimated time of submersion in water is calculated according to the method proposed by Heaton for 41 bodies whose date of submersion was known, to evaluate the method; 5 cases were excluded because they remained submerged for less than one day, so that cadaveric changes were undetectable and the ADD was not applicable.

The PMII was calculated using the ADD in 36 cases. The ADD evaluates cadaveric changes in the head, trunk and limbs, assigning a value to each region.

These regional values are added to give values of from 3 to 25 points, thereby establishing a TADS (Tables 1–3).

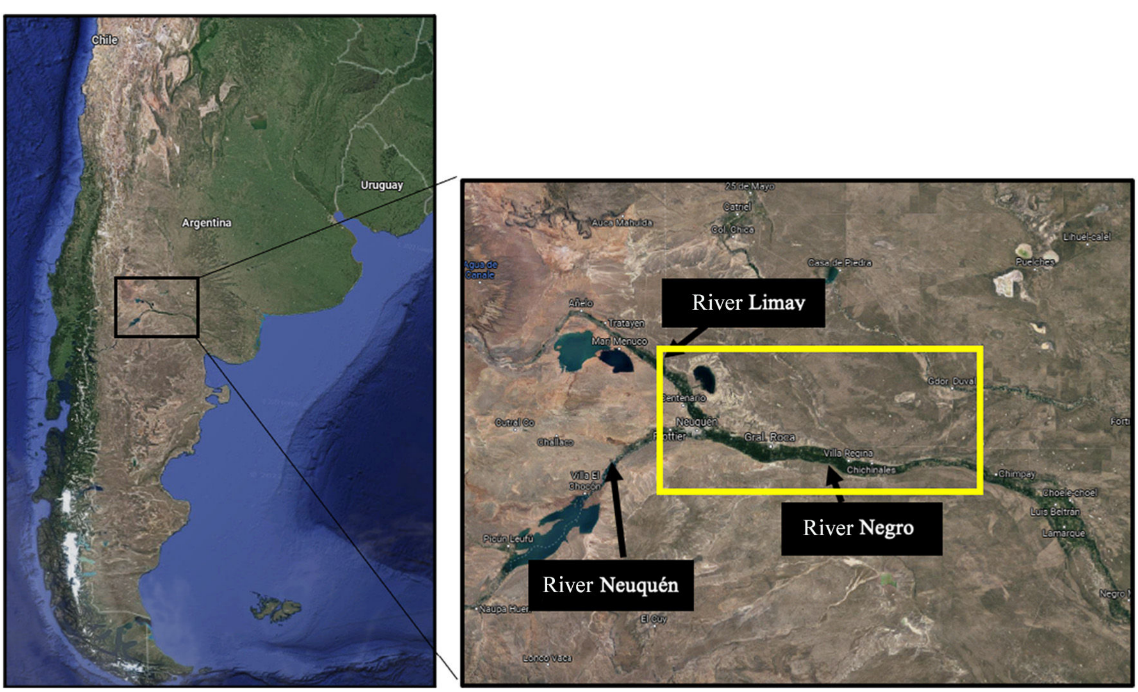


**Fig. 1** Geographical location of the study area.

**Table 1** Total aquatic decomposition score for the limbs.

| Score | Description of the decomposition of the limbs |
|---|---|
| 1 | No visible changes |
| 2 | Slight wrinkling of the skin on the hands and/or feet. Possible piloerection |
| 3 | The skin of palms of the hands and/or the soles of the feet turns white, wrinkled and thickened. Slight pinkish discolouration of the arms and legs |
| 4 | The skin of palms of the hands and/or the soles of the feet moistens and loosens. The limb marbles, predominantly on the upper part of the arms and legs |
| 5 | The skin of the hands and feet starts to peel off. Yellow/green to green/black discolouration on the arms and/or legs. Initial slipping off of the skin on the arms and/or legs |
| 6 | The skin of the hands and/or feet comes off like a glove: exposure of large areas of underlying muscles and tendons. Irregular peeling off of the skin on the arms and/or legs |
| 7 | Exposure of the bones of the hands and/or feet. Muscles, tendons and small areas of bone exposed on the lower part of the arms and/or legs |
| 8 | The bones of the hands and/or feet start to dislocate. The bones of the upper part of the arms and/or legs are exposed |
| 9 | Skeletisation and complete dislocation of the limbs |

The TADS obtained for each body corresponds with a figure which consists of the ADD prediction with upper and lower confidence intervals (Table 1 and supplementary material).

Once the ADD has been predicted, the PMII is deduced from the sum of the average daily temperatures retrospectively before the date when the body was recovered until the estimated ADD is reached. This would indicate the interval of time during which the body entered the water.

**Table 2** Total aquatic decomposition score for the decomposition of the face.

| Score | Description of the decomposition of the face |
|---|---|
| 1 | No visible changes |
| 2 | Slight pink discolouration, darkened lips, goosebumps |
| 3 | Reddening of the face and neck, visible veins on the face. Possible early signs of animal activity / predation: concentrated in the ears, nose and lips |
| 4 | Swollen face, greenish discolouration, the skin starts to come off |
| 5 | The hair on the head starts to fall out, principally on the front. The brain softens and liquefies. The tissue is exposed on the face and neck. Green/black discolouration |
| 6 | Bone is exposed: concentrated on the orbital, frontal and parietal regions. Some on the jawbone and jaw. Early formation of adiopocere |
| 7 | More extensive skeletisation of the cranium. Dislocation of the jaw |
| 8 | Complete dislocation of the cranium from the torso. Widespread formation of adiopocere |

**Table 3** Total aquatic decomposition score for the decomposition of the trunk.

| Score | Description of the decomposition of the trunk |
|---|---|
| 1 | No visible changes |
| 2 | Slight pink discolouration, darkened lips, goosebumps |
| 3 | Yellow/green colour on the abdomen and the upper part of the thorax. Speckled. The internal organs start to decompose /autolysis |
| 4 | Dark green discolouration of the abdomen, slight bloating of the abdomen, the skin starts to slip |
| 5 | Green/purple discolouration, extensive abdominal bloating: taut when touched, scrotum swollen in men, exposure of the fat and underlying tissues |
| 6 | Black discolouration, swelling that becomes softer, initial exposure of the internal organs and bones |
| 7 | Increased loss of tissues and organs, more bone is exposed, initial formation of adiopocere |
| 8 | Skeletisation and complete dislocation |

After calculating the immersion interval using the ADD method, the case is compared with others where the time they remained in the water is known.

Example of the calculation and comparison of PMII-ADD with KPMSI (case 34) (Fig. 2).

After examining the photographs and the description of the autopsy report the TADS score for case 34 was set at 13 points, which corresponds to an ADD figure of 140.6 (Table 4).

The average temperature of the river Negro in June is 10.6 °C, so that the ADD is divided by this average water temperature (140.6/10.6 = 13.2) giving a PMII by ADD of 13.2 days.

Case 34 had a KPMSI of 23 days.

The chi-squared method was used to perform a statistical evaluation of the difference between the PMII-ADD and the KPMSI.

To prepare a regional table which links cadaveric changes, water temperatures and immersion time, the photographs as well as the autopsy report description were taken into account respecting the condition of the head, trunk and limbs, and especially the palms of the hands and the soles of the feet, the presence of footwear and clothing.

The following variables were defined to evaluate the photographs:

*No changes*: when examined the cadaver had no macroscopic changes in the skin of the head, trunk or limbs, except for the presence of pale patches.

*Chromatic changes on the head and/or the trunk:* after removing the clothing and washing the skin, the colour of the skin has changed on the head or trunk. A marbled appearance or the presence of a venous network of putrefaction without bloating of the body or head.

*Initial maceration on the palms and soles:* the skin on the palm of the hands and/or the soles of the feet is white and slightly wrinkled but totally adhered to the deeper layers.

*Initial emphysematic changes on the head and/or the trunk:* increased head size with deformation of the face, protrusion of the eyeballs, swollen lips, scrotum increased in size, increased volume and pressure in the abdomen.

**Fig. 2** Photographs of the face, trunk and limbs of case No. 34.

*Clear maceration of the palm of the hands and soles of the feet:* the skin on the palms or soles is white and thickened, with areas where it is starting to become detached from deeper levels, with no lack of continuity or loosening of the nails.

*Detachment of the hair:* loss of hair or it easily comes off while manipulating the cadaver.

*Initial detachment of the skin:* the surface layer of the skin starts to detach in "patches" from the trunk and limbs.

*Deflated cadaver:* the cadaver has lax tissues in the face and the head and trunk appear to be deflated.

*Advanced detachment of the skin:* total detachment of the skin from the palms and soles, loosening and loss of nails, larger areas of the skin on the trunk become detached.

*Exposure of the deep tissues:* in some areas the skin is discontinuous with exposure of the tendons and bones, in the hands and feet at first, but also in the head and trunk.

*Skeletisation:* the body may be complete, but with clear exposure of the bones in the limbs and/or trunk and/or head.

*Dislocation:* separate fragments of the body are found with areas of skeletisation and the remains of soft tissues adhering to them.

The presence of algae was assessed on the skin layer.

Two of the authors (Gustavo A. Breglia and Marcelo H. Uzal) examined the photographs and the autopsy reports independently, and basing themselves on the definitions of the variables, and taking into account the month when the body was recovered and the known immersion time, they assigned the latter datum in the form of number of days to each variable defined for each month of the year.

They thereby created a table which linked cadaveric changes, the month of the year (with known water temperatures), and the duration of immersion in the water.

**Table 4** Example of the calculation of the Total Aquatic Decomposition Score for case 34.

| Area of the body | Description | TADS score |
|---|---|---|
| Face | The hair on the head starts to fall out, principally on the front. The brain is soft and liquefies. The tissue on the face and neck is exposed. Green/black discolouration | *5* |
| Abdomen | Yellow/green discolouration on the abdomen and upper part of the chest. Speckled | *3* |
| Limbs | The skin of the hands and feet starts to peel off. Yellow/green, green/black discolouration on the arms and/or the legs. Initial slippage of the skin on the arms and/or legs | *5* |
| Total | | *13* |

## Results

Of the 161 bodies recovered from the water, 50.3% were recovered in summer, 21.11% in autumn, 9.1% in winter and 21.1% in spring.

Of the total number of bodies recovered in 41 cases (25.4%), 33 were male (82%) and 8 were female (18%). Their average age was 34 years, ranging from 10 to 80 years.

The average time the bodies had remained in the water, expressed in days, according to the season of the year, was shorter in the warmer months. Thus in summer the duration of immersion averaged 4.6 days; in spring 5.4 days; autumn 59.8 days, and winter 20 days.

When the calculation of the PMII using ADD was compared to the known interval of immersion (Fig. 3) in 36 cases of the sample, the difference in the resulting number of days was found to be statistically significant ($P = .48 > .005$).

In 16 cases (44.4%) the known duration of immersion in the water was under-estimated by an average of 40%, and in 18 cases (50%) it was over-estimated by 41%.

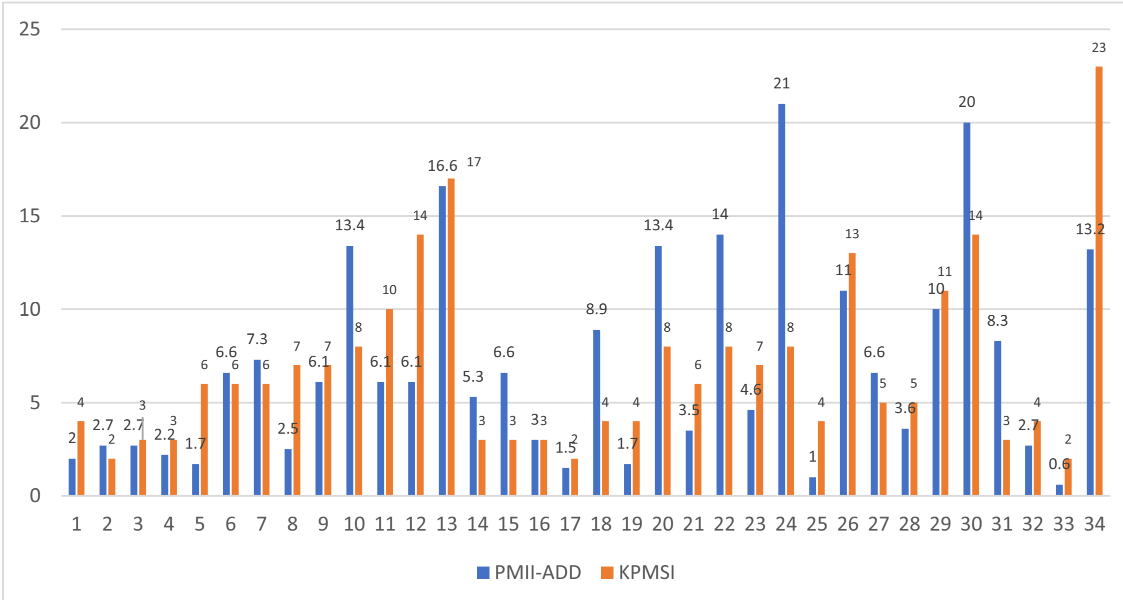


**Fig. 3** Comparison of calculation of the post-mortem immersion interval-accumulated degree days and the known post-mortem immersion interval. Two cases with known data that had remained in the water for longer than 250 days were omitted, to prevent distortion of the display of the other data.

In both situations (under- and over-estimation) the ranges were from 2.5% to 72%. The estimation of the PMII-ADD only agreed with the KPMSI in 2 cases.

Two cases had a PMII in the water longer than 5 months (156 days and 180 days); in both cases the comparison with calculation using the ADD method showed over-estimation by this method, with a figure of 272 days (from 76 to 1,079) in both cases.

In 16.2% of the cases in the sample, the immersion interval calculated by the ADD over- or under-estimated the said interval in ranges of less than 20%, taking the known immersion interval in the water as the reference.

After analysis by examination of the photographs, adjusting the described variables and with known immersion data, the data expressed in days were placed in a table that combined the months of the year with water temperatures and cadaveric changes (Fig. 2 and supplementary material).

No data were collected for August, and there was only one case with one day of immersion in the water in September.

The chromatic and emphysematic changes in the head and trunk, the loosening of the hair and the advanced detachment of the skin appeared earlier in the warmer months and water temperatures.

## Discussion

The method used by Heaton to calculate the immersion interval was considered to be an innovation, and it was validated by other authors in other locations.[8–10] Nevertheless, it was questioned for methodological reasons due to errors associated with rounding up, the temperature scale and the incorrect use of a statistical regression model which make its predictive formula unusable.[8] In the same way, other authors such as De Donno[11] used the ADD method with caution to estimate the immersion time of bodies recovered from the water, arguing that it may give a false impression of precision because of the complexity of integrating all of the changing factors which affect human decomposition in aquatic environments. These factors include currents, animal action, water temperatures, depth of submersion, age, size and clothing, as the latter may alter the temperature of the cadaver.[9–12]

The fact that several authors[3–12] propose different variables for the evaluation of cadaveric changes to establish an aquatic decomposition score shows that there is no single standardized method of assessing the said cadaveric changes.

In connection with the rivers in north Patagonia, the climatic conditions, speed of flow of the river and canals, characteristics of their banks and the possibility that bodies will be definitively snagged by the vegetation in the shade, all cause variations in the temperature and floatability of the body which may influence the cadaveric changes observed.

These morphological variations of the river and its banks may perhaps explain the variation between the results of the comparison with the ADD method. When the ADD method is compared with the known immersion interval the range of over- or under-estimation was only less than 20% in 16.2% of the cases in the sample.

In the light of these results we agree with authors like De Donno[11] that it is extremely difficult to determine the immersion interval, and that precision is impossible even when the TADS method is used. This is due to wide biological variability, to which we would add environmental variability, too.

We understand that each area studied is subject to variations in the climate, environment and water currents and temperature. These variables are not reflected in the averages taken from government agencies in the study of river conditions.

The above point may be even more evident in the Patagonian climate, where the temperature in a single day can vary greatly by 14 °C in winter and 17 °C in summer.[5,6]

This is why we believe that the method proposed by Reh[1] and validated years afterwards by Doberentz,[2] which combines the observed cadaveric changes with water temperature, has withstood the passage of time. It is not distorted by complex logarithmic calculation variables, it is based on the observation of changes in a cadaver within the context of a known medium and temperatures.

This table which was originally proposed by Reh can clearly not be extrapolated to other locations, even more so when the latter are in another continent and hemisphere, with a different climate and geography.

Therefore, and based on this methodology, we carried out a retrospective re-removal of 41 bodies recovered in our area of study with reliably knowledge of their immersion interval.

Although the number of bodies recovered from the water in our area of study over 15 years is not small (161 cases), this study may be questionable due to the weakness arising from the low number of cases with a known immersion interval (41 cases), the lack of records from the colder months and the poor documentation of the data which make it possible to know the total immersion interval of the bodies recovered from water.

To better estimate the time a body recovered from the water has been immersed, we believe that the degree of skin maceration and emphysematic changes in the head and trunk should be assessed at the moment the body is removed from the water. This is because changes progress rapidly once it has been extracted from the water, more so in the summer months, and this may lead to erroneous estimation if the said changes are measured when the autopsy takes place days or even hours later.

We have detected this situation in our area of study, where sometimes the distance between the site where the body was recovered and the morgue involves hours of transport in unrefrigerated vehicles.

Ideally the forensic doctor should show in his report the date on which the individual whose body was recovered from the water disappeared. When reliable data about when the body entered the water are available, this will aid carrying out retrospective studies based on more reliable data. This study of 161 bodies recovered from water found sufficient data for an appropriate study in 41 cases.

We consider the strength of this study to lie in the creation of a table to estimate the length of time a body has remained in water. This table is regionally applicable in the water courses of the Upper Valley of the River Negro in Patagonia Argentina. It is completely dynamic, so that it is possible to complete it prospectively with data, so that it will be possible to adjust the estimation of immersion intervals.

We understand that the data on intervals in the table presented here should not be extrapolated to other water courses, even when the average temperatures are similar. This is because variations in the climate (temperature amplitudes and wind patterns, etc.), water currents, depth and bank characteristics may give rise to intervals that cannot be compared with those in another area under study.

## Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.remle.2023.03.005.

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