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This is an **author produced version** of a paper published in:

Historical Biology (2023): 1-7

DOI: <https://doi.org/10.6084/m9.figshare.22101992.v2>

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How to quantify taphonomic alteration? A novel index for fossil fish collections.

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How to quantify taphonomic alteration? A novel index for fossil fish collections.

Several biases are often introduced in taxonomic studies due to the transformation or loss of biological information that occurs at different stages from the original depositional ecosystem to the finally selected study sample. We propose the creation of a Taphonomic Alteration Index for Fishes (TAIF) that allows an estimation of the extent of such transformation in the selected sample and its representativeness of the complete record. TAIF is designed as an easily-applicable index that can be used to rapidly assess and compare the taphonomic alteration in different taxa or localities and can also be used as a quantitative variable in other analyses (e.g., morphometrical, statistical). To test TAIF, we have used a sample of Teleostei *incertae sedis* (N=190) from the Early Cretaceous of the Las Hoyas site (Cuenca, Spain). Although the obtained TAIF values show some variability, they are in general low, as would be expected for a Konservat-Lagerstätte. The low TAIF values obtained fit with the hypothesis that these fishes inhabited low energy and shallow inland waters, where the effect of anoxia and bacterial sealing would have preserved their remains from degradation. Similar indices could be designed for other taxa based on TAIF.

Keywords: taphonomy; preservation; conservation; fossil fishes; biases; Las Hoyas

Subject classification codes: 80th anniversary of Effremov's Taphonomy

Introduction

In fossil deposits we find a specific taxonomic abundance and a quality of preservation that determines the fidelity with which the fossilized biological entities represent the ecosystem of the past (type 1 bias: preserved remains). From the set of fossils that are found in the deposits, the collected ones constitute the collections that we find in museums or research institutions (type 2 bias: fieldwork collection). Finally, when we carry out a study we select the most suitable specimens for the intended analyses, therefore introducing new biases because often the selected sample is not completely

representative of the collection in terms of the amount of information that it provides (type 3 bias: study sample, Figure 1). In each of these stages, from the original ecosystem to the study sample, transformation and loss of biological information occurs, along with a gain of taphonomical information, which directly translates into potential biases (model of taphonomic modification and differential retention; Fernández-López 1991). [Figure 1. Near here]

In that regard, Rascón Perez et al. (2011) presented an index that easily allowed quantifying the loss of biological information in human osteological remains in contrast with other detailed indices proposed (e.g., Stojanowski et al. 2002). For that purpose, they created a variable called ‘State of Taphonomic Alteration’, which measures the completeness of the skeleton and the quality of the preservation of the bone.

Completeness was defined as the number of anatomical units preserved summarized in three categories: complete, partially complete, or few osteological remains. Bone quality refers to the state of preservation of the bone classified in three categories: unaltered bone, partially altered, or altered. The combination of these categories results in nine states of preservation that could be contrasted with other variables such as age, sex, and the presence of pathological characters.

Following the index designed by Rascón Pérez et al. (2011), the present work aims to propose a new index to evaluate the taphonomic alteration in fossil fish collections. This index will be denoted as TAIF, the acronym for Taphonomic Alteration Index for Fishes. In order to evaluate the applicability and utility of TAIF, we have tested it with a collection of fossil fishes from the Konservat-Lagerstätte of Las Hoyas (Early Cretaceous, 126-129 Mya, Marugán Lobón et al 2023). Through this example, we will test a few of the wide range of utilities of TAIF. We will use the index to check whether the exceptional preservation that characterizes the fossil record of Las

Hoyas is also observable in particular in the record of teleostean fishes (bias type 1). Additionally, we will evaluate whether there is a discernible bias in the sampling protocol along the over three decades of excavation at this locality based on taphonomic differences (bias type 2). Lastly, we will utilize the resulting TAIF values to explore the extent of the biases that are introduced in the selection of samples for taxonomic purposes (bias type 3).

Materials and methods

The proposed methodology is based on three steps: first, the selection of appropriate variables to evaluate taphonomic alteration; second, the indication of the state of each variable in each specimen; and third, the use of the results to test the solvency of TAIF with respect to different biases that can be encountered in the fossil record.

Sample

To test the solvency of the index, a sample of teleostean fossil fishes from the paleontological deposit of Las Hoyas (upper Barremian, Cuenca, Spain) were chosen. This site is considered a Konservat-Lagerstätte because of the quality of preservation, diversity, and abundance of the fossils found there (Buscalioni and Fregenal 2010; Buscalioni and Poyato-Ariza 2016, Marugán Lobón et al. 2023). The teleostean fossil fishes constitute the most abundant group of vertebrates in the locality (over 4000 specimens) with evidences of exceptional preservation (Poyato-Ariza 1997; 2005; Poyato-Ariza and Martín-Abad 2016b), which have allowed several taphonomic studies (Gupta et al. 2008; Poyato-Ariza and Martín-Abad 2016a; Carazo et al. 2021). Therefore, it is an appropriate sample to test the suitability of the variables considered in the proposed TAIF.

We have selected 190 specimens, currently identified as Teleostei *incertae sedis*, implying that their specific determination and phylogenetic position are still unknown. These fishes are characterized by a small size (about 1.5-4 centimeters length), fusiform bodies, short fins, absent or small teeth, and well-developed gill rakers (Figure 2). The collection is stored at the Museo Paleontológico de Castilla-La Mancha (MUPA, Cuenca, Spain) and represents laterally flattened fishes preserved in laminated limestones with some of them (n=53) preserved in two parts as slab and counter slab. To maximize the representativeness of the sample, six boxes were selected out of the 164 boxes that constitute the collection, one every 30 boxes, to include specimens that were collected in different fieldwork campaigns throughout the over 30 years of excavation at the locality since 1985. Isolated elements such as scales or fragments of bones were not included since TAIF cannot be applied to these specific cases. All the fossils of the sample (included slabs and counter slabs) were photographed with a digital camera model Canon SX510HS.

[Figure 2. Near here]

Taphonomic Alteration Index for Fishes: TAIF

TAIF is envisioned as taking into account every morphological evidence that implies a taphonomic modification from the original organism. However, in its design, we have prioritized ease of application as well in order for it to be an easily utilizable tool rather than a complicated, time-consuming calculation. We have selected the most relevant variables commonly observable in teleostean fossil fishes to easily assess their overall degree of taphonomic alteration: completeness, degree of articulation, preserved tissues, and curvature. A detailed description of each variable is provided below:

- **Completeness:** measured as the presence of anatomical units. We have identified seven anatomical units in teleostean fossil fishes: cranium, axial axis, dorsal fin, pectoral fin, pelvic fin, anal fin, and caudal fin. In the case of paired fins, it would only be necessary to see at least one of the fins to determinate their presence since it would be enough to be able to extract information about the anatomy of the structures. Completeness is therefore calculated as the number of identifiable anatomical units out of the seven that can be present in the same individual.
- **Articulation:** measured as the number of anatomical units that have maintained their anatomical position (i.e., each of them in relation to the axial axis). The degree of articulation of an anatomical unit that is not present cannot be evaluated, and therefore, articulation is calculated as the ratio of anatomical units ~~preserved and~~ articulated out of those that are preserved in order to avoid redundancy with the variable Completeness (i.e., an individual with few preserved anatomical units, but with all of them articulated would have a high articulation value, Figure 2J).
- **Preserved tissues:** presence of structures that are not commonly preserved in fossil fishes but that are often observable in exceptionally preserved specimens. We have also prioritized elements that could prove important for taxonomic or other kinds of studies: eyes soft tissue, body contour tissue, extremes of fin rays, and gut contents. Absence of scales has been demonstrated to be a good indicator of abrasion due to nekrokinetic movements even in low energy systems (Martín-Abad and Poyato-Ariza 2016a); however, we have not included them in this variable because their absence is not necessarily a result of taphonomic alterations (i.e., fish can shed scales due to numerous events in their

life; additionally, it can also be the result of ontogenetic or taxonomic differences). This variable is calculated as the number of the elements that are present out of the four elements mentioned.

- Curvature is often the result of a tetany process during the biostratigraphic phase caused by the contraction of the ligaments and muscles due to decay (Elder 1985). This variable considers whether there is curvature (0) or not (1) into the possibility to determinate the presence of curvature (1) or not (0). If the curve cannot be evaluated because of incompleteness of the specimen (mostly absence of axial axis), the score will be 0, and this specimen will be treated as missing value in density plots (see Results, Figure 3B).

The ratio between the summation of the scores observed in each variable and the summation of the total scores that could be observed represents the percentage of non-alteration of the fish. The final Taphonomic Alteration value is the inverse of this percentage. These percentages are categorized into five categories (1: 0-19.99%; 2: 20-39.99%; 3: 40-59.99% 4: 60-79.99%; 5: 80-100%), where higher categories include specimens with greater taphonomic alteration. A visual example of the calculation of TAIF is provided in the Supplementary Data.

Intraobserver error of the taphonomic alteration has been measured with the Cohen's kappa statistical test (Cohen 1960) using function *cohen.kappa* (Revelle 2022) in R software (R Core Team 2022) to evaluate the agreement in the assignation of TAIF categories to specimens. We conducted the TAIF procedure for two samples of 25 and 50 individuals in three different times (once every two weeks). The results show that between time 2 and 3 the agreement in the assignment of TAIF is almost perfect, indicating a minimal intraobserver error. Therefore, the sample was re-measured once so that the expected intra-observational error is the minimum. We have also checked in

how many cases the same TAIF value is obtained for the two slabs of those specimens preserved as slab and counter slab.

To facilitate the collection of data, we have designed a Google quiz that includes short questions concerning the different variables; a quiz is completed for each specimen. A complete dataset can be easily obtained by repeating the process with all the sample. The answers are transduced into numeric values to calculate TAIF by a purposely programmed script using the free R software. The R code is freely available in the Supplementary Data.

Assessing the presence of biases

First, to evaluate whether the fish sample shows the exceptional preservation that characterizes the locality (related to type 1 bias), two approaches can be followed: by specimens or by the whole sample. The former is evaluated through the frequency of individuals (frequency tables) and the distribution of variables (density plot) in each TAIF category. The later can be assessed providing the numerical mean value of taphonomic alteration for the whole sample.

Second, to test whether there is a collection bias based on the taphonomic alteration of the fossils (type 2 bias), we have performed a linear regression of the collection number of each specimen (as an estimator of the time when fossils were collected) against TAIF percentages values.

Finally, we have calculated two more variables to test the presence of biases that could affect taxonomic studies (type 3 bias). We have termed them Potential Geometric Morphometrics Sample (PGMS) and Potential Meristic Sample (PMS). PGMS summarizes which specimens can be used in a geometric morphometrics analysis to study the shape of the cranium, the post-cranium, and the relative position of the fins following the criteria used in previous studies (Cavalcanti et al. 1999; Cawley et al.

2018; Liyandja et al. 2022). PMS indicates the specimens in which it is possible to count the number of vertebrae; the dorsal, pelvic, anal and caudal fin rays; and hypurals, because of their extended use as diagnostic characters in taxonomy of fishes (Nelson et al. 2016), and particularly in basal teleostean lineages (Arratia 2015).

Results

The results of testing TAIF with Las Hoyas teleostean fossils suggest that over half of the test sample has a low state of taphonomic alteration (states 1 and 2), whereas less than a quarter of the sample present a state of great taphonomic alteration (states 4 and 5) (Figure 3A). Figure 3B illustrates the combination of variable states that comprise each TAIF value in our study. It shows the frequency of individuals for each percentage of completeness, articulation, tissue preservation, and curvature (for the latter, only two possible percentages can be obtained: curved (0%) or not curved (100%)).

In state 1, the sample is characterized by 85%-100% of completeness, being fully articulated, and 100% of anatomical units preserved. Six specimens show three out of the four preserved tissues, 15 specimens show two out of the four. About 57% of the sample show curvature.

In state 2, a higher variability of distribution can be observed between variables. Completeness ranges from nearly 50% to 100%, the most frequent value being 71.43% (=5/7). Anatomical units are completely articulated except for a few specimens that show from 50% to 83% of articulation. The value of tissues preserved ranges from 0% (no features) to 50% (two out of the four features preserved). Most of the specimens where curvature can be assessed are indeed curved (56 out of 60 specimens).

In state 3, there are no individuals with all anatomical units preserved, with values of completeness ranging from 42.86% (3/7) to 71.43% (5/7). However, in 51

specimens all anatomical units that are preserved are articulated. 12 specimens show two out of the four preserved tissues, 21 show one, and 24 show none. 84% of the fishes where curvature can be evaluated are indeed curved.

In state 4, only 14.29% (1/7) to 42.86% (3/7) of the anatomical units are preserved, but in 28 out of 29 specimens all of them are articulated. Part of the specimens (37.93%) show one out of the four tissues preserved, while 62.07% of the specimens do not show any of them. Ten specimens are curved, while two are not and the rest do not preserve the axial axis. Therefore, it is not possible to evaluate their curvature.

In state 5, the anatomical units preserved are lower than 25%. A value for the degree of articulation cannot be provided in those cases where the axial axis is not preserved. Therefore, only six specimens could be evaluated with four of them being fully articulated while two of them show the only unit preserved (in this case, the cranium) disarticulated from the axial axis. Tissues preserved are 25% or less. Curvature can only be evaluated in three out of the 14 specimens with the three of them being curved.

Altogether, these profiles can be used to describe tendencies for each of the variables. In our sample, when there is an increase of taphonomic alteration, completeness decreases, but the anatomical elements remain highly articulated even at stronger alteration states. No specimen preserves all the exceptional tissues, but most of the individuals present at least one of them. Fossil fishes with curvature are observed from state 1 to 5. The TAIF average value of the whole sample is 2.72.

The analysis of correlation between TAIF values and the collection number of the specimens (used as a proxy for the time of collection) is significant ($p < 0.001$), being less altered than those collected in later years (Figure 4, Table 1). However, the

R^2 coefficient indicates a low degree of correlation between alteration and time ($R^2=0.136$). In 19 of the 53 specimens where both slabs were used, different taphonomic alteration states are found between slab and counter slab (e.g., Figure 2K, L). [Figure 4, Table 1, Near here]

Regarding the selection of individuals that could be used in other studies depending on their state of preservation, Figure 3C shows that the specimens that comply with the criteria to be included in a PGMS correspond to 25.26% of the total sample, whereas the specimens that can be used for PMS are 8.97%. Only 7.89% of the sample can be used for both kinds of studies. No specimens with states 4 and 5 of alteration can be used as PGMS; likewise, no specimens of states 3, 4, and 5 can be used as PMS.

Discussion

Previously quantitative proxies have been applied in fishes to study taphonomy (Whitmore 2003; Chellouche et al. 2012; Pan et al. 2015), but most of them evaluate taphonomic evidence in each anatomical element, not being able to provide a single value per individual or per sample. TAIF has been proposed as a quantitative estimator of the taphonomic alteration of an individual and of a complete sample. The versatility of the information extracted from the index allows its use for different purposes. We have used a sample of teleostean fossil fishes from the Las Hoyas deposits to evaluate taphonomic biases in different phases of taphonomical alteration (Fernández López 1991).

Biases type 1 can be addressed by TAIF as shown in Figure 3 and by the single TAIF value given for the whole sample. For example, in this case, the exceptional preservation that has been repeatedly discussed as a main feature of Las Hoyas fossil record (Buscalioni and Fregenal Martínez 2010; Guerrero et al. 2016) is herein

confirmed in particular for the sample of Teleostei *incertae sedis*, highlighted by the preservation of soft tissue in most of the specimens and the high degree of articulation of anatomical units (Figure 3B). Considering that the values of TAIF range from 1 to 5, the value obtained for Las Hoyas sample, 2.72, is relatively low; however, it might be slightly higher than expected for an exceptional preservation deposit. This fact can be attributed in part to the criteria applied for specimen storage and conservation; not only the best-preserved specimens are collected, but also those of lower quality due to their taxonomic rarity or stratigraphic significance, among other factors. In this sense, collection procedures and/or biases will affect the TAIF value of a given assemblage; therefore, TAIF values can be useful for comparing different assemblages and for detecting different excavation methodologies related to storage and conservation strategies.

Regarding bias type 2, significant differences in taphonomic alteration have been found in our sample associated with the increase of the collection numbers (used as an estimator of time of collection). However, the low R^2 coefficient indicates that fishes with different degree of taphonomic alteration are collected over the years. It is also important to note that during each excavation campaign conducted in Las Hoyas, multiple sampling areas of diverse stratigraphic levels are explored. Hence, in some cases there is no direct correlation between the number of years of excavation and the stratigraphic level of the sampled areas. Nonetheless, TAIF can also be used to analyze whether there is a correlation between preservational characteristics and stratigraphic provenance of the specimens, which in turn will allow contrasting hypotheses such as the different preservation that could be found between the wet and dry seasons (i.e., environmental alternance) described at Las Hoyas (Buscalioni and Fregenal Martínez 2010).

Finally, bias type 3 has been evaluated by calculating the proportion of the sample that could be used in geometric morphometric and meristic analyses with taxonomic purposes. TAIF has revealed that in the sample from Las Hoyas, teleosts with high TAIF values will be discarded in morphometrical studies. As a consequence, species and/or ontogenetic stages that might present a differential preservation and, thus be more poorly preserved, would be underrepresented in taxonomic studies.

Although summarizing the characteristics in a single numerical value may seem an oversimplification of taphonomic information, TAIF also allows us to know which values of each of the variables characterize each of the categories (see Figure 3B). TAIF is robust because although there might be some variability in the state of the variables that make up each category, this variability is limited since the combinations of the variables are ultimately providing a percentage of alteration (e.g., TAIF category 1 ranges from 0% to 19.99% of alteration). For example, a fish with a level 4 of TAIF will never be fully complete and articulated.

In our case, TAIF results show that completeness is the variable that fluctuates the most. However, the absence of anatomical units is due to both the effects of the fossilization of the organism (preservation) and the extraction and conservation of the specimens (Cambra-Moo et al. 2022, 2023). For example, in the specimen in Figure 2B, the caudal fin is coded as absent because that part of the rock is missing; however, its presence could not be guaranteed even if that part of the rock was present. The same occurs with Figure 2E, where the skull seems to be covered by sediment. Therefore, the incompleteness of an individual should not be immediately interpreted as worse preservation. In this case, it is likely that a high percentage of fishes do not preserve anatomical units due to problems of exposure and conservation (e.g., preparation), since

in those where only a part of the organism is observable, this part presents a high quality of preservation (Figure 2C).

Slabs and counter slabs are not mirror images of one another, so different TAIF values can be expected. In our results, this has also been confirmed, and this can be explained mostly due to part of the tissues (anatomical unit or preserved tissues) being preserved in just one of the slabs (Figure 2K, L).

In Las Hoyas, TAIF indicates that most of the Teleostei *incertae sedis* exhibit a high degree of articulation and preservation of soft tissues and delicate elements (Figure 3B) suggesting optimal condition for fossilization. This evidence agrees with Carazo et al. (2021), whose study of mass mortalities of Teleostei *incertae sedis* from Las Hoyas reflects slight orientations of the bodies likely due to the presence of gentle currents in a low energy system. Besides, hypotheses of rapid burial (Buscalioni and Fregenal Martínez 2010), bacterial sealing (Gupta et al. 2008; Buscalioni and Fregenal Martínez 2010; Iniesto et al. 2013; Guerrero et al. 2016) and anoxia events (Carazo et al. 2021) proposed for the Las Hoyas ecosystem would support the general low taphonomic alteration of the teleostean fishes. However, these optimal conditions for fossilization would not always be constant, providing variability in TAIF values. Precisely, these events of anoxia have been proposed as a cause of tetany that produce the contraction of ligaments shortening the backbone (Elder 1985; Viohl 1990, 2015; Marramà et al. 2016; Pan et al. 2019), which could explain the common presence of curved fishes in Las Hoyas (e.g., Figure 2A, D, L). However, other factors seem to mediate the post-mortem curvature: dehydration by salinity or alkalinity (Seilacher et al. 1985), heat shock (Elder 1985), gas accumulation in the abdominal cavity (Chellouche et al. 2012), and the length and degree of ossification of the backbone (Biénkowska 2010; Poyato-Ariza and Martín-Abad 2016a; Pan et al. 2019). Future studies should delve into the cause of

curvature exhibited by specimen from all TAIF categories following what has been done in other deposits (Biéńkowska 2010; Chellouche et al. 2012; Pan et al. 2015; Marramà et al. 2016).

In conclusion, TAIF has been devised as a tool to quantify the taphonomic alteration in a collection of fossil fishes that can be used as a quantitative value to help easily provide an overall assessment of its preservation, discuss the taphonomic characteristics of a fossil assemblage in relation to other factors (e.g., sedimentology, stratigraphy), and compare different localities. The solvency, versatility, and ease of application of TAIF shown in this study might inspire future adaptations to other taxa so that this type of index is extensively used to evaluate the taphonomic characteristics of samples and localities.

Disclosure statement

The authors report there are no competing interests to declare.

Acknowledgements

The authors acknowledge the Museo Paleontológico de Castilla-La Mancha for facilitating access to the Las Hoyas collection. We would like to express our gratitude to the three reviewers of the manuscript and the editor Dr. Gareth Dyke for their exhaustive and constructive review which have contributed to improve the present paper.

Funding

This work was supported by the Spanish Government under Project PID2019-

105546GBI00; and the Department of Biology, Universidad Autónoma de Madrid, under Project BIOUAM02-2019. Carla San Román is supported by a FPI-UAM Ph.D. scholarship from Universidad Autónoma de Madrid.

Data availability statement

The data that support the findings of this study are openly available in figshare repository at <https://doi.org/10.6084/m9.figshare.22101992.v2>

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Captions.

Table 1. Regression scores of the lineal regression model of the percentages of taphonomic alteration against specimen number collection (time).

Figure 1. Taphonomic biases in the fossil record. Part of the ecosystem is registered as biological entities that fossilize and are recorded in paleontological deposits (bias type 1). During excavation campaigns, fossils are extracted and stored in museum collections (bias type 2). Samples are selected from museum collections depending on the methods that will be used for their study (bias type 3).

Figure 2. Representative Teleostei *incertae sedis* from Las Hoyas: (A) MUPA-LH-13338b; (B) MUPA-LH-28156; (C) MUPA-LH-35318; (D) MUPA-LH-14076a; (E) MUPA-LH-35100; (F) MUPA-LH-13359b; (G) MUPA-LH-13563a; (H) MUPA-LH-16056b; (I) MUPA-LH-3835b; (J) MUPA-LH-36264b; (K) MUPA-LH-16646b; (L) MUPA-LH-16646a; (M) MUPA-LH-3066a. Scale bars represent 1 cm.

Figure 3. (A) Frequency table and bar plot of the distribution of specimens in TAIF categories (TAIF level 1 represents lower alteration, level 5 higher); (B) Density plot of the distribution of completeness, articulation, preserved tissues, and curvature in each TAIF category. Y axis is scaled to show frequency in order to facilitate interpretation; (C) Bar plot of the distribution of specimens in TAIF categories comparing the distribution of total sample in yellow, potential geometric morphometric sample (PGMS) in red, potential meristic sample (PMS) in blue, and both PGMS and PMS in black.

Figure 4. Regression scores of the percentage of taphonomic alteration against the specimen numbers of collection as an estimation of time; in black the linear regression fit. Colors represent the five categories of taphonomic alteration.

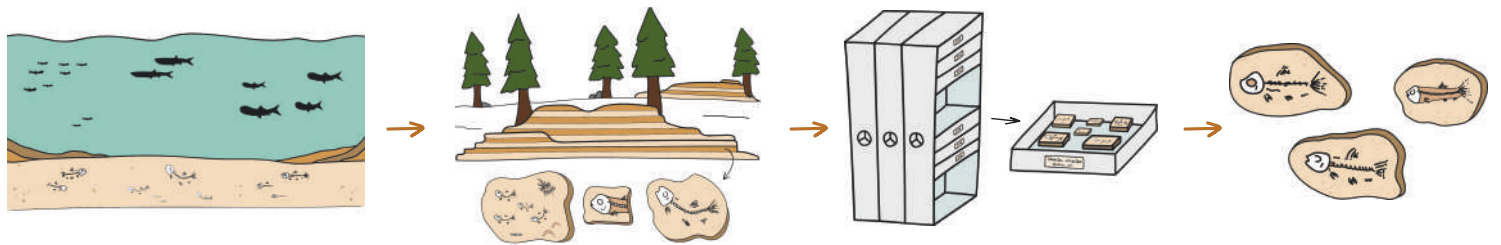
Supplementary online material.

Figure 1. Three examples of step by step calculation of TAIF values. For each specimen, the degree of completeness, articulation, preserved tissues, and curvature of the body are evaluated.

In completeness, a total of seven anatomical units have been defined, so 7 is the maximum value for this variable (indicated in the blue column). The number of anatomical units actually preserved for each specimen is indicated in the pink column. Articulation is calculated as the anatomical units that are articulated with the axial axis, so the maximum value (also in the blue column) is 6; however, articulation cannot be evaluated for the structures that are not preserved, so in this variable the maximum does not always need to be 6. For example, in specimen MUPA-LH-14076b, the five anatomical units that are preserved are articulated with the axial axis (cranium, dorsal fin, pectoral fin, pelvic fin, and caudal fin); in this case, the anal fin because is not taken into account because it is not preserved. The preserved tissues variable includes four elements (eyes soft tissue, body contour tissue, extremes of fin rays, and gut contents), so this variable is calculated as the number of these elements that are present, the maximum value being 4. Curvature is coded as a 0 (in the blue column) when it is not possible to evaluate it (e.g., MUPA-LH-35318). If the curvature can be evaluated, it will be coded as a 1 in the blue column, whereas the pink column will show a 1 if the body is not curved (e.g., MUPA-LH-13338b) and a 0 if it is curved (e.g., MUPA-LH-14076b).

Percentages of taphonomic alteration are calculated as 100 minus the percentage of non-alteration, which in turn is calculated as the sum of the scores observed (in the pink column) divided by the sum of the scores that can be evaluated (in the blue column) x100. Finally, the percentages of taphonomic alterations are categorized into five categories to obtain the final TAIF values (1: 0-19.99%; 2: 20-39.99%; 3: 40-59.99% 4: 60-79.99%; 5: 80-100%), where 1 represents a fossil with a low degree of taphonomic alteration and 5 represents a fossil with a high degree of taphonomic alteration.

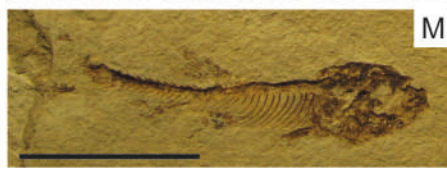
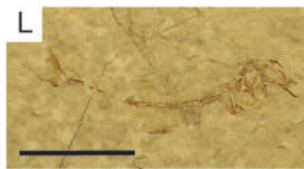
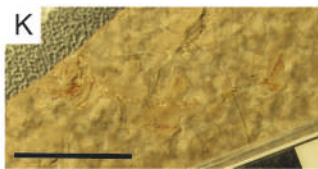
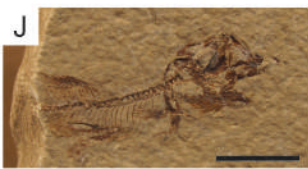
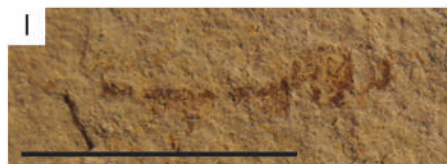
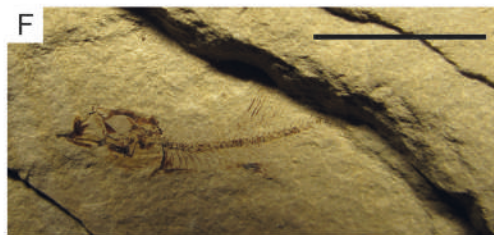
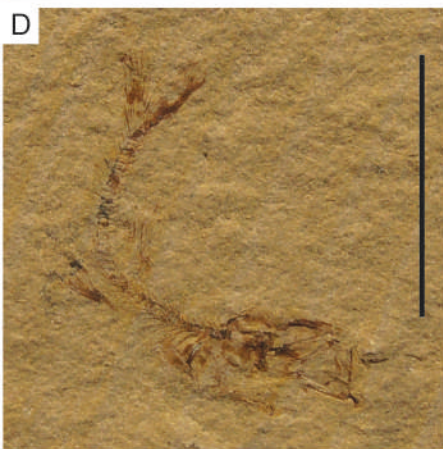
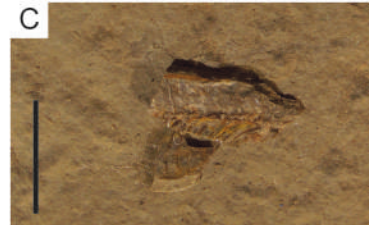
Table 1. Mean value and standard deviation of Cohen's kappa statics in TAIF category assignment to specimens. A sample of 25 specimens and 50 specimens were measured three different times independently. According to agreement categories, time 1 vs 2 and time 2 vs 3 show a fair agreement of TAIF states assignation in both samples, whereas in time 2 vs 3 show substantial agreement in the sample of 25 specimens and perfect agreement in the 50 specimens.



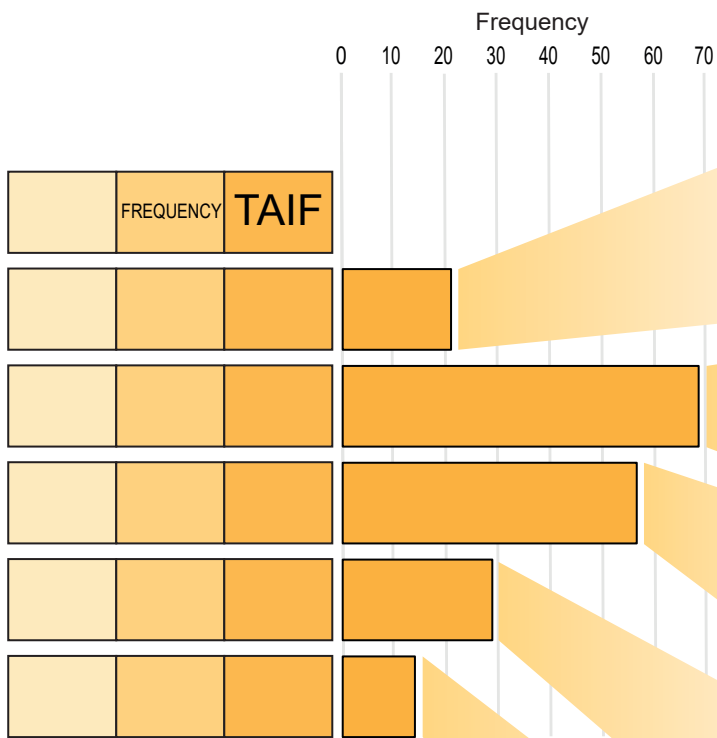
BIAS TYPE 1
Preserved remains

BIAS TYPE 2
Fieldwork collection

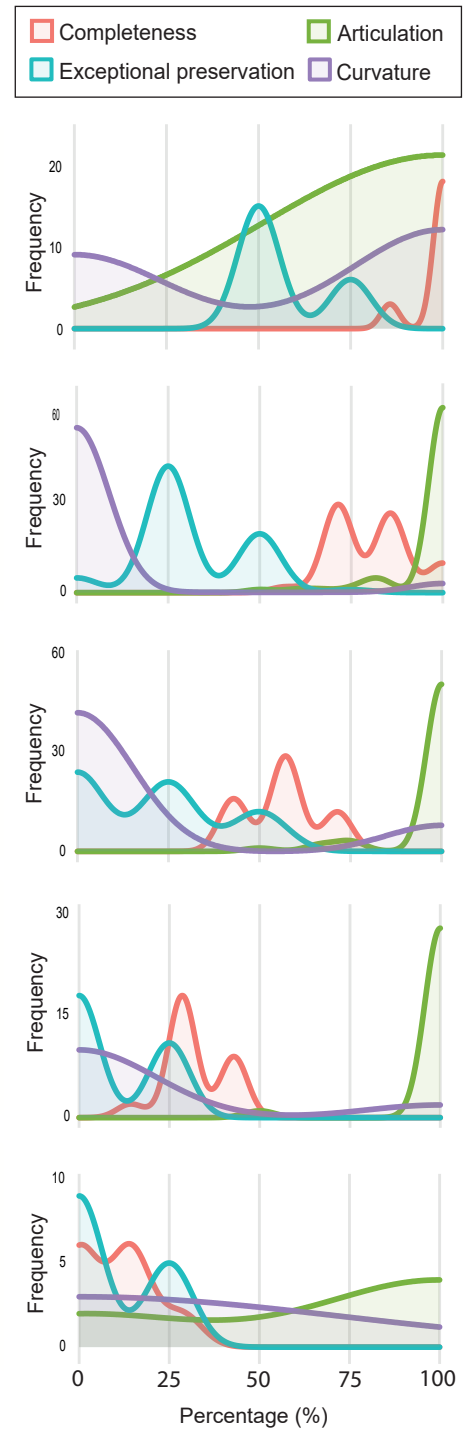
BIAS TYPE 3
Study sample



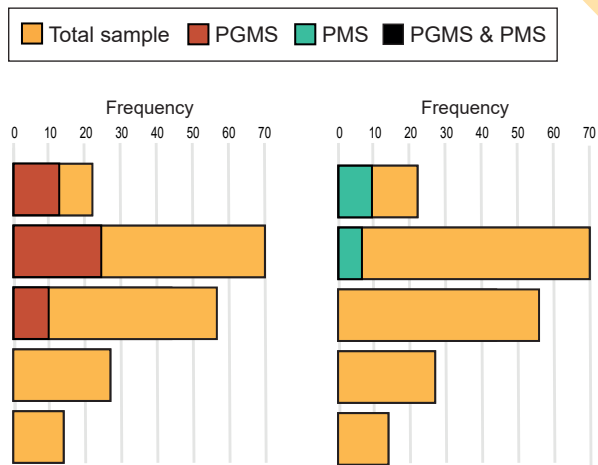
A

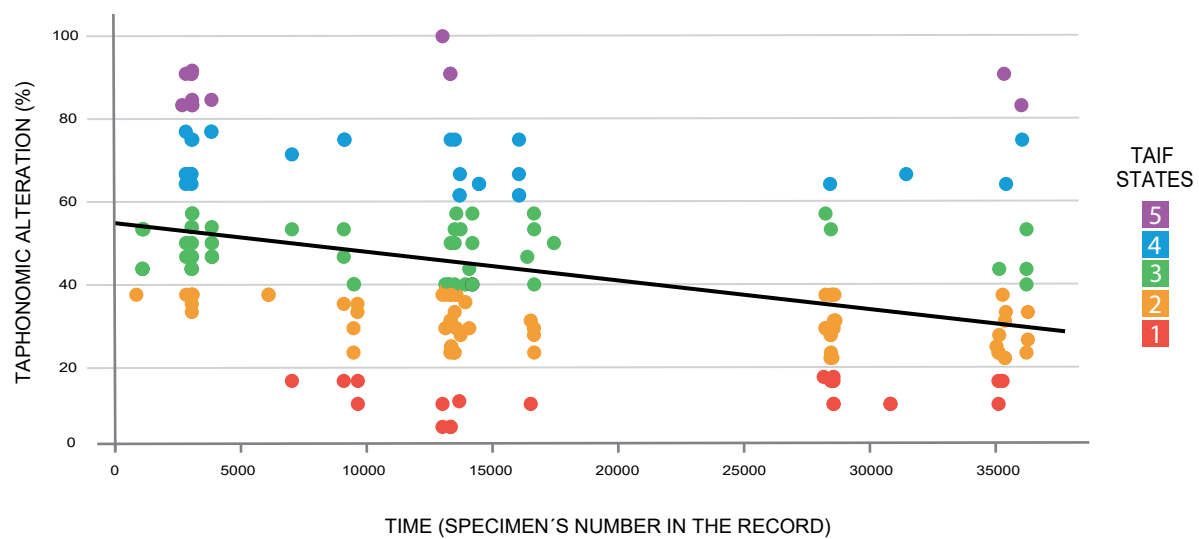


B



C

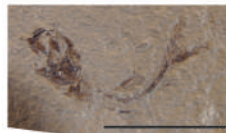




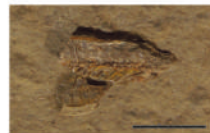
MUPA-LH-13338b



MUPA-LH-14076b



MUPA-LH-35318



Completeness

7 / 7

6 / 7

1 / 7

Articulation

6 / 6

5 / 5

0 / 0

Preserved tissues

3 / 4

1 / 4

0 / 0

Curvature

1 / 1

0 / 1

- / 0

↓ ↓

17 / 18

↓ ↓

12 / 17

↓ ↓

1 / 7

Non-alteration

94.44%

70.59%

14.29%

↓ (100 - 94.44)

↓ (100 - 70.59)

↓ (100 - 14.29)

Taphonomic alteration

5.56%

29.41%

85.71%

Taphonomic state

Category 1

Category 2

Category 5