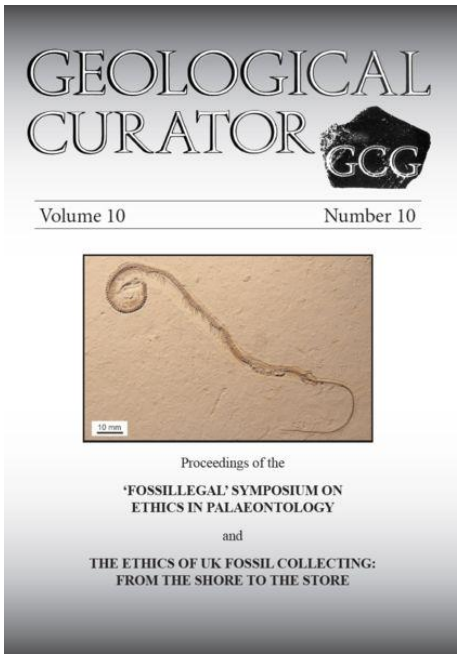

Site-specific limitations on the use of palaeontological resources

Palaeontological resources are used by many people for diverse purposes, and in generating a best practice model for utilisation and conservation of these sites, the requirements of all of these interested parties should be taken into account. Fossil bearing sites vary tremendously, especially in rates of depletion of the rock and fossils, frequency of visits by interested parties and the scientific significance, size and distribution of fossils therein. We argue that it is these criteria that should dictate best practice for any particular site, and in doing so a far more rational conservation strategy can be achieved.

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SITE-SPECIFIC LIMITATIONS ON THE USE OF PALAEONTOLOGICAL RESOURCES

by Charlie J. Underwood and David J. Ward

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Palaeontological resources are used by many people for diverse purposes, and in generating a best practice model for utilisation and conservation of these sites, the requirements of all of these interested parties should be taken into account. Fossil-bearing sites vary tremendously, especially in rates of depletion of the rock and fossils, frequency of visits by interested parties and the scientific significance, size and distribution of fossils therein. We argue that it is these criteria that should dictate best practice for any particular site, and in doing so a far more rational conservation strategy can be achieved.

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Introduction

The use of fossil resources has become an issue that provokes strong emotion in many palaeontologists. The perceived best practice for conservation of fossil resources has frequently been used to guide changes in the legal status of fossil collecting of various types within a country or other province. This is despite palaeontological and other geological sites being highly variable. The degree and application of legal protection of fossil sites varies tremendously with geopolitical boundaries, at least in part due to the experiences and perceptions of advisors contributing to the discussion from which the legal 'protection' derives. Where legal protections for palaeontological resources exist, as is the case for most of the World, the laws often lack flexibility and are thus inappropriate in a large proportion of cases. Many fossil protection laws, especially in countries with a rich archaeological heritage, are based on archaeological heritage laws which mostly inappropriate to palaeontological resources. While the legal protections of fossils should be adhered to, if these laws are detrimental to the optimum utility of fossil resources, pressure should be applied where possible to gain improvements made to laws.

Shimada *et al.* (2014) rightly point out that the last few decades represent a golden age for palaeontology. We would like to suggest, however, that this would be better be described as a second golden age, with the mid-late 19th Century representing the first. The 19th Century saw great advances in palaeontology and vast numbers of specimens being acquired by museums around the World. This early blooming of palaeontology occurred when there were very few professional palaeontologists, and contributions from amateurs and commercial collectors were essential. Despite this, there is often a reluctance today to replicate the cooperation that allowed so much palaeontological progress in the past.

Overall ethos

We strongly consider that a fossil that has been of benefit to society, be it through scientific advancement, education, bringing pleasure and stimulation or helping to financially support a community, is vastly preferable to one destroyed and lost forever.

Uses of field palaeontological resources

Field based palaeontological resources are extremely varied, and no two exposures, or even parts of the same exposure, are exactly alike. They vary in size, lithology, rate of erosion and weathering, as well as fossil content, all of which will profoundly influence the best practice for the optimum utilisation of the resource. In addition, it should be acknowledged that the use or utilisation of these palaeontological resources is highly variable, with different parties having a greater or lesser interest in different palaeontological sites.

Academic research

Academic research is typically considered the prime use of palaeontological resources, with material being either studied *in situ* or, more commonly, removed for study in museums or other academic institutions (commonly universities and geological surveys). This focus on academia may be to the extent that other users and interested parties are, or may perceive they are, ignored, marginalised or otherwise prevented from use of the resource. From the standpoint of the gaining of scientific information, it is generally acknowledged that academic use of fossils and the sites from which they were obtained is of paramount importance, and other uses should be regarded as secondary. Results of these academic studies, and often the specimens themselves, may subsequently be available to the general public but this is rarely the primary aim. Despite this, it must be realised that research collection by workers from research institutions does not exist in isolation, and the divisions between categories of usage of fossil sites are rarely clear cut. Failure to acknowledge this has the potential to do palaeontology as a science a great disservice, denying it potential contributors, data and funds. This even has the potential to alienate academic palaeontologists from the general public who have a vested interest in their research, not least considering that most palaeontology is funded, directly or indirectly, by the general public.

Hobbies and continued outreach

Finding, observing and collecting fossils can be a very significant hobby or pastime amongst adults and children who are not directly linked to academia. This is especially so in Europe and North America, where collecting of this sort has remained well established since the days of 18th Century curio collections, pre-dating organised scientific research on fossils. This mode of use of palaeontological resources can vary in scope from the occasional collection of fossils when the collector is in a suitable area, to a major life direction with the collector spending uncounted hours collecting, preparing and curating material. In some cases, often for reasons of access to field sites or interest in fossils that may be rare, collectors may supplement their own activities with, or specialise in, purchased or traded material.

There are benefits of this as a hobby for the individual and for society at large. Whilst the individual benefits from the stimulation of collecting or working with fossils, society and academia may benefit in many ways. A large number of non-academic palaeontologists contribute greatly to the science of palaeontology. Many such people donate specimens (often collected at great personal cost) to museum collections. Some individuals may even publish scientific studies on material they have collected and may provide field and lab assistance to academic researchers. Consequently, some non-academic palaeontologists have publication rates rivalling those of museum and university workers, and may also rival them in the number and significance of fossils received by museums. In addition, many chose to specialise on particular field sites, often local to them, and as a result have far greater opportunity to find newly exposed specimens than academics who are unable to spend the same amount of time on the ground. Combined with this, some collectors have a specialisation in a site to an extent that academics would be unable to replicate, and this allows some non-academic palaeontologists to develop the specialised skills for finding, collecting and preparing fossils from a site that exceed those of any less frequent visitor (e.g. Steve Etches in the Kimmeridge Clay).

Whilst the argument can easily be made that a fossil in a private collection is useless to science, and may even be considered as 'lost' by more extreme academics, in many cases this is not the case, at least not in the long term. Many, although certainly not all, collectors are happy to collaborate with academics as long as they are made to feel welcomed on equal terms, and many will donate the most scientifically useful specimens to public collections (often at financial loss to themselves). Furthermore, specimens in private collections are rarely destroyed, and even when material is not donated by the collector, there is always the potential that specimens will be donated after their death. It should however be acknowledged that many collections 'disappear' after the death of the collector, being discarded or sold as décor items without data. The failure for specimens to be correctly donated to museums may commonly be seen more as a failure on the part of academia to publicise their willingness to work with the estates of collectors, than the estates themselves.

Non-academic palaeontologists or collectors thus constitute a vast reservoir of manpower, expertise and specimens (e.g. Catalani 2014, Sole 2007, Sole and Etches 2005, Underwood *et al.* 2016). They commonly have collections that include scientifically important material, but many collectors are willing to work with academia and donate this material. Whilst important specimens may be lost after the death of a collector, these specimens would not have otherwise been collected and so it can be argued that even if some specimens are lost to science, the net gain far outweighs the loss.

Education and science outreach

The importance of education and outreach should never be underestimated. Many children have a great interest in science and the natural world, and palaeontology can be seen as one of science's public relations successes. Not only can it be regarded as a gateway to natural history, earth science and science in general, but it is of great importance in its own right. Many academic or other professional palaeontologists acquired their interest at a very young age and a large proportion probably collected fossils as a child.

Palaeontology can form an important forum for challenging some of the main sociological problems associated with science. At a time where denialism of scientific facts is commonplace, palaeontology can play an important role. Whilst we are unaware of any data on the subject, it would be expected that children exposed to palaeontology, especially in the field, would be far more likely to be able to critically evaluate the natural world and thus less likely to accept non-scientific concepts such as creationism and anthropogenic climate change denial. There is also a major issue with gender inequality in both research and applied science. The authors' experience with outreach activities with children suggests that amongst primary school-age children, interest in palaeontology is equally prevalent amongst boys and girls. As such palaeontology may be regarded as a 'gateway' into science for girls and encouragement at an early age may have the potential to influence subject preferences later in the school career.

Whilst there are invaluable learning opportunities with fossils in museums and other collections, field palaeontology adds an extra dimension and adds a contextual awareness of fossils. At some field sites, fossils are clearly displayed in the rock and may provide an exceptional visual teaching and learning resource. At other sites fossils are small and found loose and thus are most readily accessed by collection of small specimens (see case studies of Charmouth and Abbey Wood, below). This taps into the love of collecting that is demonstrated by many children (and adults) and provides material that can be kept as a reminder of the visit, or to form the basis of subsequent work in the classroom. In most cases these fossils will be common and of already known scientific value and the outreach and educational importance of these specimens vastly outweighs their (perceived) loss to science. Experienced oversight of collections made may identify any rarities discovered and alert the finder to the potential for donating them to a museum.

Tourism

Fossils can add greatly to a local economy in a variety of ways. This may be through geotourism, with geological heritage, including fossils, as the main aim of the visit, or in the form of less focussed visits where fossils are an added attraction to people primarily in the area for other reasons. While geotourism focuses on palaeontological and other geological resources, often for a period of a number of days, this tends to be the domain of a relatively small number of people in specialist interested groups. Casual interested parties are potentially far larger in number and, in areas otherwise open to tourism, can provide a far greater income. Whilst seeing impressive fossils *in situ* is clearly an attraction for both groups, the ability to collect fossils may be equally important, and if *in situ* fossils are not suitably impressive to the general public, the ability to collect and keep fossils may be the sole draw to these people. Indeed, whilst there are few holiday destinations that use the presence of *in situ* fossils or other geology as a selling point, the availability of fossil collecting is listed as part of the main attractions for a number of holiday destinations (see case study of Charmouth, below). While the draw of being able to collect fossils cannot easily be given a monetary value, if the presence of fossils is considered sufficiently important for tourist authorities to use as promotion material, it is likely that they contribute significantly to the attraction of the venue. Casual fossil hunting can therefore be regarded as contributing significantly to the economy of some towns and regions.

Commercialisation of fossils

The collection of fossils for sale alone is a highly controversial issue amongst palaeontologists. Hostility towards all commercial fossil collecting and dealing has commonly been expressed (e.g. Shimada *et al.* 2014, and in many bar-room discussions at palaeontological conferences), but palaeontology as a science also benefits from this trade (e.g. Larson 2001, Larson and Russel 2014, Martill 2001, Nudds 2001). The collection of fossils for sale has a very long history and has played a pivotal role in palaeontology. Fossils have been collected for sale since the start of palaeontology as a science, and the vast majority of collections of fossils from 19th Century Europe were largely or entirely from commercial sources. To this day many research institutions regularly purchase fossils, which in many cases allows them to obtain specimens to which they would otherwise fail to have access; indeed, commercial collecting could be regarded as outsourcing of specimen collection, which could be far more

financially viable than organising excavations, particularly in the current political climate for institutional funding.

The outcomes of individual acts of collection of fossils for sale may vary from very negative to the science of palaeontology (such as removal of known specimens before they could be scientifically excavated) to very positive (collection of fossils that would otherwise be destroyed and allowing a research institution to purchase them). Less well understood are the wider implications of making fossils into a commodity. It has been suggested that giving fossils a monetary value encourages all collectors to view fossils as a commercial resource rather than for their scientific value, and this may prevent specimens from being donated that would have been donated otherwise. To our knowledge there is no data to demonstrate that this is the case. It is possible that this idea may be more prevalent amongst those inheriting fossil collections than those who accumulate them, but again data is lacking. It has also been suggested that trade in smaller fossils, such as shark teeth from sites where they are common, has increased collection pressure on more vulnerable sites by making such fossils more desirable. Again there is no data for or against this, and there has been a counter suggestion that, for example, large scale sales of Moroccan fossil shark teeth has depressed the price of fossil shark teeth to the extent that ad hoc commercial collection of more vulnerable sites is not financially viable. Indeed, in this case there is a suggestion from sales of shark tooth jewellery that low cost fossils have made use of modern teeth unviable, potentially reducing hunting pressure on modern sharks.

Shimada *et al.* (2014) quote the Society of Vertebrate Paleontology bylaw "The barter, sale, or purchase of *scientifically significant* vertebrate fossils is not condoned, *unless* it brings them into, or keeps them within, a public trust" (our emphasis). We would agree that this is a very desirable position but even this would be best not taken as an inflexible rule. There are situations, for example, where funding from sale of some (possibly potentially important) fossils allows continued excavation or rescue allowing more specimens to become available for research, so the 'loss' of some fossils provides a net gain overall (e.g. see the Oued Zem case study below).

Exposure, collection and destruction

Maximising the utility of palaeontological resources, and allowing the greatest degrees of freedom to a range of interested parties, is largely dependent on the rate at which fossils are being destroyed versus the frequency of visits to the site. It is only by weighing up the relative importance of these criteria, as well as taking into account the types and sizes of fossil present, that an ideal model for usage of a site can be arrived at. Variations in these criteria may result in any optimisation of usage model being not only site specific, but bed or exposure specific (Edmonds *et al.* 2005, Larwood 2001).

Rates of fossil exposure and destruction

The rate at which rocks are destroyed by natural or anthropogenic processes varies tremendously, as does the degree to which this destruction is episodic. Whilst it may be useful to separate natural or anthropogenic destruction (Edmonds *et al.* 2005), in terms of overall optimum recovery of fossils, it makes little difference other than that the former is more predictable. As rocks are destroyed, fossils are initially exposed and then they too are destroyed. If fossils are relatively large and/or more robust than their enclosing rock, there is likely to be a period between exposure and destruction of a fossil when it can be seen on the rock surface. The exposure of fossils for collection or *in situ* study is therefore controlled by the rate of exposure due to erosion and weathering and the timing and rate of destruction of the fossil. The period between exposure and destruction represents the residence time during which the fossil is accessible. The fossil may have a lower rate of destruction than the surrounding rock and erode from it intact. The fossil is then subject to both continued destruction by erosion and weathering, but also to transport, removing the fossil from its geological context. In general, the longer that a fossil has been exposed, the more information has been lost from it, through destruction or damage of exposed parts of the fossil, removal of contextual information in surrounding rock or, in the case of fossils freed from the matrix, loss of data on stratigraphical position. For these reasons, newly-exposed fossils typically yield more palaeontological data than those that have been exposed for a long period.

Collection and destruction rates (see Fig. 1)

Unless collected by directed mining, fossils can only be collected or studied once exposed by erosion, weathering or human activity, and prior to their destruction by the same processes. Different fossil sites, and different exposures and beds within specific sites, are thus subject to a series of variables that will dictate the likelihood of a fossil being destroyed prior to collection or study; rate of exposure, rate of destruction of fossils and frequency of visit by palaeontologists or other interested parties. When destruction of the rock precedes destruction of the

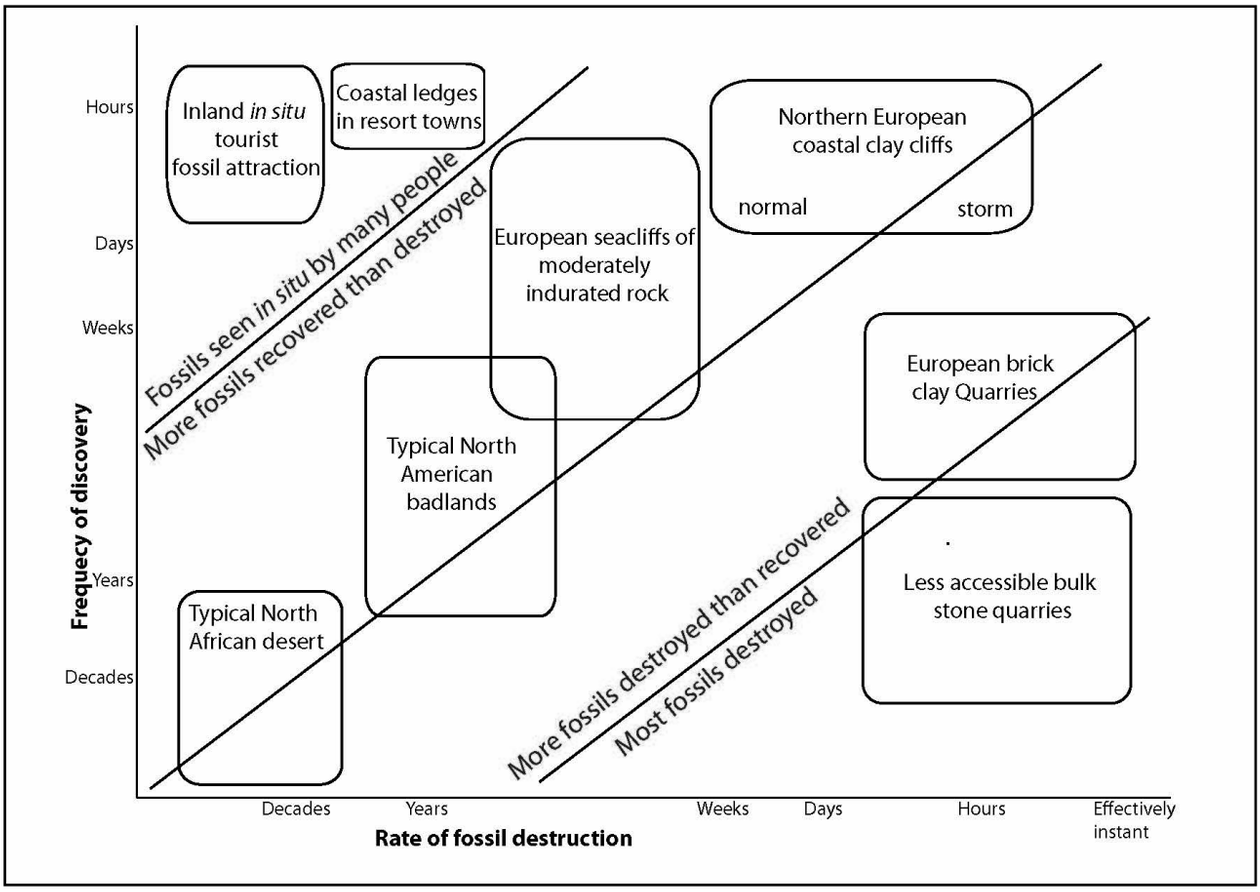

Figure 1. Plot of rates of fossil destruction and fossil discovery, showing fields where most fossils are destroyed and where most are retained.

fossils, an additional variable is introduced, namely the time between removal of the fossil from its matrix and its destruction. During this period the fossil is still accessible but is of vastly reduced scientific value.

The rates of exposure and fossil destruction vary dramatically between fossil sites. Coastal cliffs of non-indurated mudstone may erode at a rate of several metres a year, with much of that erosional loss often being during a relatively brief period of storms and/or exceptional tides with loss reaching rates of many tonnes per hour during these events. Well indurated rocks on the same piece of coast by contrast may undergo essentially no destruction for many decades, before catastrophic failure by erosional removal of large rocks. Natural inland exposures typically have lower destruction rates, but unconsolidated rocks within badlands that undergo relatively high rainfall may erode at relatively high rates, especially near drainage courses. In contrast, lithified rock in highly arid areas may be destroyed at extremely low rates with little appreciable change over millennia. Man-made exposures also typically have very high rates of fossil exposure and destruction. In bulk rock quarries, rock may be removed as it is exposed and as such the residence time (time between their exposure and destruction) for fossils is effectively zero, at least in working faces. In exposures such as road and other cuttings, the initial extraction of rock and enclosed fossils may be extremely rapid, with almost no subsequent exposure. In addition, many such cuttings are ephemeral and may be backfilled, covered or otherwise obscured almost immediately after their excavation.

Not only is the time that fossils are available extremely variable between different sites, so is the frequency of visits (of people actively engaged in palaeontology) to the site. Whilst there are large areas of potentially fossiliferous exposure that have never been prospected for their palaeontological content, there are tourist destinations where there may be thousands of person/visits to a particular area each year. Where the residence time of fossils is less than the frequency of visits, more fossils will be destroyed than available for examination. Where residence time of fossils is considerably greater than the frequency of visits, conspicuous fossils have a very high probability of being noticed. As a fossil destroyed is of no use to academia or any other potentially interested parties, we suggest that it is on these variables that best practice for maximising utility of fossil sites should be based. As these variables are likely to be

such that no two sites are identical, the application of inflexible 'one size fits all' codes of practice or laws are likely to be harmful to maximising use of fossil resources in more sites than they are beneficial. As a result, attempts to produce generic codes of conduct for fossil sites fail when (for example) indurated Palaeozoic and unconsolidated Cenozoic rocks are covered together (DJW Personal observation).

Maximisation of utility of exposures

As small and slowly eroding exposures of fossiliferous rock are most prone to damage, it is important that damage is minimised. Whilst sensitive sites of this type *could* be the most likely to be considered the preserve of directed research collecting, there may be cases where even this may be regarded as inappropriate, where the scientific gains are more than offset by the damage to the site and the reduction of the utility of the site to other interested parties at that time or in the future. As exposures become progressively more fragile and prone to damage, it becomes more important that maximum scientific outcomes are to be obtained for any damage caused. Collection that requires the removal of considerable quantities of rock, such as digging out a particular fossiliferous bed or excavation of a large vertebrate fossil, can be particularly destructive, not only in the damage caused to the exposure but also in the obscuring of other parts of the exposure by spoil. In these circumstances, care should be taken to remove the minimum amount of rock and try to prevent other parts of the exposure being obscured by spoil. In the case of large scale, and damaging, excavations, the onus should be on the collector to maximise the data from the excavated material. Matrix of large specimens, as well as spoil, should be considered as important resources and treated accordingly. Where the lithology allows, matrix and spoil should be thoroughly investigated for additional, small, fossils. In many cases this could be best done by passing unconsolidated or chemically treated sediment through appropriate sieves. This may yield large samples of smaller ("meso") fossils such as microvertebrates, small molluscs and disarticulated echinoderms. Smaller samples should be processed, where appropriate, for microfossils and can also be used for sedimentological study. Whilst less spectacular than the large, targeted specimen, these collections may prove to be more scientifically significant.

Microfossils and bulk sampling

As noted above, a large amount of important information from any site is in the form of very small specimens. These commonly yield large amounts of palaeontological data, and may be very species rich and thus are likely to add significantly to the importance of a site. As such, fossils are too small to be readily collected without specialist methods, all fossils of this type would ultimately be destroyed unless bulk sampling is used. As well as microfossils in the classically accepted sense, this includes what could be referred to as mesofossils; specimens too small to be readily collected individually in the field but too large to appear in meaningful numbers in microfossil residues. Collection of samples for microfossil processing typically causes very little damage to a site as the quantity of material is generally very small. There are probably relatively few sites where the integrity is likely to be damaged by microfossil sampling and so this should often be regarded as acceptable even when collection of larger specimens is not. Samples for mesofossils are typically larger, and may range from a few kilogrammes to well over a tonne. As these fossils are not readily seen in the field, removal of mesofossil-bearing rock may occur with little information as to the yield of the samples. Careful sampling will not harm the utility of the site for those interested in macrofossils as long as the sediment is removed in such a way as to not damage the integrity of the site itself. If mesofossils are disseminated through a rock and samples can be collected without influencing the appearance of the site, quite large samples can be extracted from even potentially vulnerable sites without lasting damage. If these fossils are concentrated in a particular targeted level, such as a thin shell or bone bed, then extraction of even a relatively small sample can adversely influence the utility of the site by cutting into a particular horizon, or generating quantities of spoil. Greater care must thus be taken in sampling these levels. It could therefore be considered that sampling for microfossils, and careful sampling for mesofossils, should be encouraged for a large proportion of sites as there may be very high scientific gain for little or no visible damage to the site.

Retention of specimens and data

The scientific utility of palaeontological specimens is only as good as the data associated with them. Without collection data a specimen has use as a taxonomic specimen, or for studies related directly to the morphology of the specimen, but there is little more applied study that can be performed. In contrast, a specimen with full collection data may be in addition used for study of the geological context (such as biostratigraphy and palaeoenvironmental analysis) as well as palaeobiological context (such as palaeoecology). This data is also essential in placing the taxonomic study into an evolutionary timeframe. Data should therefore be collected as fully as possible, and also stored in such a way that there is redundancy to cover data loss in the future. Full data

should ideally therefore be kept with the specimen, but also published alongside any description of the material to allow for the potential of loss from the museum. ***Publication of full field data, including precise stratigraphical and geographical information, thus not only insures reproducibility, an essential cornerstone of all science, but also acts as a data storage backup***. We consider that full disclosure of this data must be regarded as the default situation, and retention of some of this information only be considered in very exceptional cases.

Long term specimen storage is an essential part of care of palaeontological resources. Storage of specimens should ideally allow both ready access and long term safety. It has been argued (Besterman 2001) that fossils may be regarded as part of the heritage of a country or region, and as such there is also an argument for storage of specimens close to their site of collection. A more pragmatic, and probably scientifically valid, reason for retaining specimens close to their source is that it is far easier for researchers to be able to visit a locality and the fossils from it within a single trip. The preferred institution for storage may therefore have to be a compromise between locality, access and safety. As the primary scientific concern should be for the safekeeping of the specimen, safety of the specimen should be considered an overriding criterion if such a choice is possible. Even the best museums, however, may lack permanency. Whilst closure of public institutions should not place specimens at risk if contingencies for removal to another institution are in place, destruction of an institution and/or its contents are possible, as was the case for many European palaeontology collections during 1939-45, and archaeological collections in Iraq and Syria in the early 21st century. The 2018 destruction of the National Museum of Brazil in Rio de Janeiro by fire clearly demonstrated that war is not a prerequisite for destruction of entire museum collections. Smaller scale events such as minor fires or floods may also destroy specimens and/or the data associated with them. It should therefore be considered that, where duplicate specimens exist, some should be kept at a second institution, preferably in another country. Whilst this may directly contradict commonly held notions of sovereignty of heritage, it is suggested here that palaeontologists should place the wellbeing of specimens above geopolitical dogma. For example, the loss to science of palaeontological specimens in the National Museum of Brazil fire was made far worse by the absence of duplicate specimens within other museums elsewhere due to heritage laws preventing fossil export.

Case studies (see Fig. 2)

While the range of different parameters influencing the best practice exploitation of palaeontological sites are seemingly infinite, the situations at some well-known and classic sites provide a good range of case studies. The sites below vary in their rate of destruction, frequency of visit and access. In each case, criticisms can be made but also some best practice can be seen. Similar critiques of other sites can be seen in Edmonds *et al.* (2005). Several of the sites are in the UK, where what we consider to be good practice is widespread; it has been noted before that "a congenial and civilized working relationship still exists today in England [presumably referring to all of the UK] between commercial "professional" collectors and museum and university academics" (Larson and Russell 2014).

Active bulk rock quarries; Oued Zem phosphorite mines, Morocco.

The phosphorite deposits of northern Morocco comprise some of the largest reserves of sedimentary phosphate known, and form the basis for a vast industry in phosphate extraction and fertiliser manufacture. The phosphorites are highly condensed and range in age from Maastrichtian to Ypresian. While the majority of shelly fossils have been taphonomically lost, vertebrate fossils are exceptionally abundant and sometimes well preserved. Tetrapod remains comprise both isolated teeth and bones and partial to complete skeletons. Mosasaurs, crocodilians and chelonians dominate, but many other groups including pterosaurs, birds, mammals and dinosaurs are also known. Fish and shark remains are most commonly preserved as isolated teeth and bones, but some partial skeletons of both chondrichthyans and osteichthyans are known. At most stratigraphic levels, small teeth of sharks and rays are the dominant fossils, and may be present in the rock at frequencies of many tens of teeth per kilogramme.

The open cast quarrying of phosphate concentrates on levels which have little lithification (known locally as Couches), with intervening calcite-cemented horizons being largely stockpiled. Phosphorite is sent for milling and processing very soon after extraction. The vast tonnage of fossiliferous material extracted contrasts with the very small number of visits to the site by palaeontology researchers. The majority of visiting researchers are based outside Morocco, and historical agreements between the mining company (OCP) and a small number of research institutions has effectively prevented access to most workers from outside these agreement institutions. Whilst the current situation allows only a tiny proportion of sig-

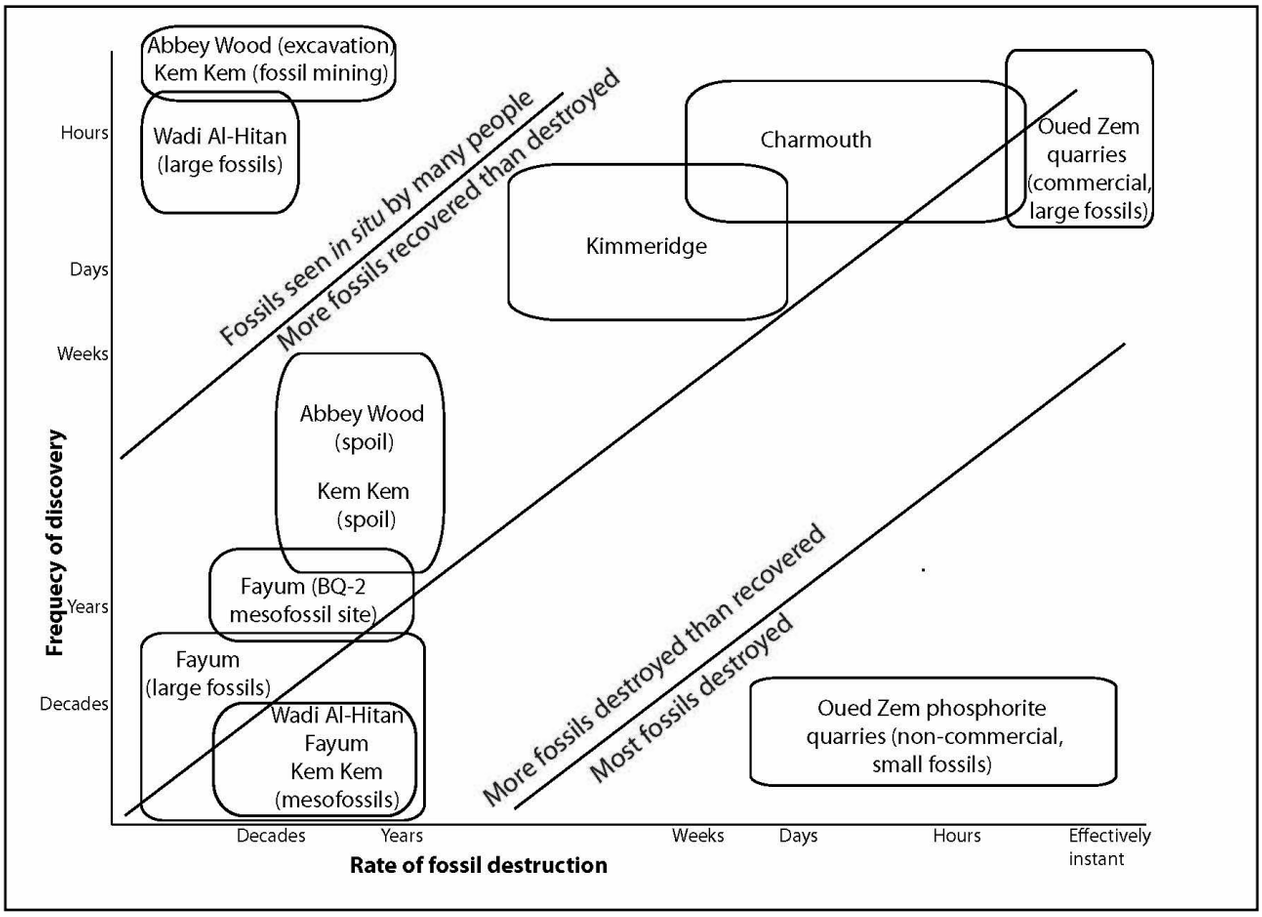

Figure 2. Plot of rates of fossil destruction and fossil discovery as in Figure 1, with case study sites superimposed. Note that only at Abbey Wood and Fayum site BQ-2 are mesofossils regularly sampled for.

nificant fossils exposed to be directly collected by researchers, a flourishing local market in fossils has allowed vast numbers of specimens to be made available through private enterprise and fossil shows around the world. It is these commercial routes that have been the source of the great majority of scientifically described tetrapod and large fish specimens, rather than through the cartel of French institutions.

Commercial exploitation focuses on fossils with a monetary value; tetrapod remains, especially skulls, are especially sought after, with some small scale adits being dug in disused parts of the mines to exploit mosasaur rich levels. There is also a large, and possibly larger, market in shark teeth, from both the Cretaceous and Paleogene. Where levels are suitable for dry sieving, sediment is passed through coarse (8-10mm mesh) sieves to recover lamniform shark teeth along with some ray, fish and tetrapod bones and teeth. The bulk of this material is initially sold by weight, later being graded and the most attractive specimens removed, many to be used in jewellery production. The teeth of *Otodus* are targeted due to their size, whilst teeth of the rare Paleocene genera *Palaeocarcharias* and *Notidanodon* are targeted for the collector market. A strongly lithified level at the base of the Eocene is discarded by the phosphate mining operation, but is especially rich in large *Otodus*, and so is manually broken up in the search for these teeth. In the process, this collecting has yielded a large proportion of the rare bird and even rarer mammal fossils known from the site.

There is no dedicated natural history museum in Morocco, and so specimens retained within the country have been deposited in a few university collections, the long term curation of which is uncertain. There is currently a museum owned by the OCP being developed to host fossils from the phosphorites, but again the long term status of such a private museum is open to question. The legal status of the fossils is somewhat vague and currently in a state of flux. The fossil industry clearly supports a large number of people in the otherwise impoverished area, and supplies vast numbers of fossils to researchers and enthusiasts alike. There are rules in place preventing the export of some significant specimens, but we have never been able to get these adequately explained. All shipments of fossils from Morocco are currently checked and signed off by the Ministry of Mines, and so in theory at least all specimens are legally exported as long as they are in a registered shipment. However, in 2016 a specimen of a plesiosaur offered for sale in Europe got a lot of

press interest both within and outside Morocco. This has led to calls for a change in the legal status of fossils, and meetings have been helpful to that end, but the outcomes are currently unknown. We strongly consider that any change in the law would be disastrous for palaeontology, both scientific and aesthetic, as well as the local economies of parts of Morocco, and would ultimately result in fossils that would otherwise have been collected being turned into fertiliser.

Slowly eroding remote inland cliffs; Kem Kem escarpment, Morocco.

Alongside the phosphorites, the most significant source of important vertebrate fossils from Morocco is the so-called 'Kem Kem Beds'. The Kem Kem Beds comprises fossiliferous fluvial sandstones of mid Cretaceous age (Albian-Cenomanian) that crop out beneath an escarpment along the north, east and south sides of the Tafilalt basin. The name Kem Kem refers to the southern hamada, but is generally used by palaeontologists to refer to the rock unit that is present there. While the outcrop is extremely extensive, relatively few sites are exposed due to landslips and rockfalls of the overlying Akrabou Formation limestones, with large areas inaccessible due to proximity with the Algerian border. The erosion rate is extremely slow, with rain being a rare occurrence and the overlying limestones forming a very resilient cap to the succession, protecting the softer sandstones and mudstones below. Fossils of fish, aquatic tetrapods and dinosaurs have been known from these rocks since 1938 (Choubert *et al.* 1952), but it is only in the 1990's that extensive commercial exploitation began. Some large fossils, generally of dinosaurs, have been collected by academic field parties from remote areas not easily accessed by local people (e.g. Sereno *et al.* 1996). It is probable that initial discoveries, both academic and commercial, were of specimens weathered out of rocks or preserved *in situ*, but these were quickly exhausted. From that point, the vast majority of fossils have been excavated by small scale mining. The majority of fossils are disarticulated and isolated bones and teeth, typically preserved within channel lag deposits. Mines are up to three metres vertically or 100 metres horizontally. They are unsupported and fatal accidents have occurred. Some mining operations, such as the commonly visited sites near Begaa in the south, target smaller and more robust dinosaur teeth and *Onchopristis* rostral denticles within coarse channel lags, with other fossils being a bonus. The majority of the fossils collected are thus of little scientific importance (as opposed to the smaller number of highly significant finds excavated alongside), but allow collectors of all ages and types to own some dramatic specimens without endangering more sensitive sites. It is from one of these mines that the supposedly associated bones of *Spinosaurus* (Ibrahim *et al.* 2014) originated. In all sites, more scientifically significant finds (as opposed to dinosaur teeth and *Onchopristis* denticles and indeterminate crocodile and turtle material) occur at very low frequencies, and it is very unlikely that these would justify the time and costs of a researcher-led excavation.

The Kem Kem area is frequently visited by academic researchers as well as geotourist and undergraduate groups, but most visits are brief, in part due to the remoteness of the area (two days of driving from any international airport). Whilst finds of large fossils were initially made, the small amounts of exposure within the more readily accessed eastern area suggest that these would soon have been removed, and not replaced by erosion, even if there had been no commercial collecting. The mining activity has been the source of virtually all of the fossils described in numerous publications from the site. In addition, the spoil of the mining operation is rich in commercially valueless fossils (due to size or preservation) and collecting these is a major attraction and resource for researchers (looking for small rarities), geotourists and student groups alike. Sieving of some spoil material (CJU and DJW personal observation) has yielded important specimens of hitherto unknown sharks, fish and tetrapods. Wholesale dealers in the area are generally very knowledgeable about the fossils and will actively seek out particular specimens on request if they are required for research.

The excavations of the Kem Kem are a dramatic boost to the local economy, both through fossil sales and through visitors attracted, in a very impoverished desert area. Sites that have been dug will not 'repair' through erosion for a considerable period of time, though seasonal heavy rains can erode rapidly. However, exposed sites are small whereas the area of outcrop is vast and so any damage is spatially very limited. Despite this, the scientific benefits of the fossil industry are vast, with many people benefiting in one way or another from the fossils being available on the open market and locally.

Coast with rapid erosion; Charmouth cliffs, Jurassic Coast World Heritage Site, UK.

The coastal cliffs of western Dorset, on the British South Coast, have become justifiably famous for their fossils over the centuries. It is from this area that Mary Anning collected fossils and became probably the most famous commercial fossil collector of all time. The combination of the diversity of geology, rich palaeontological heritage and coastal scenery of

this area earned it UNESCO World Heritage Site status in 2001. The Jurassic Coast World Heritage Site produces large numbers of important fossils and has been referred to as "the only World Heritage Site you can hit with a hammer" (Page 2006; the quote presented in a negative manner).

The lithologies, and rates of erosion of different parts of the Jurassic Coast vary dramatically, but the cliffs either side of the town of Charmouth represent the most rapidly eroding part of the Dorset coast. The cliffs are high and comprise Early Jurassic (Sinemurian-Pleinsbachian) mudstones capped by unconformable Cretaceous sandstones. Along this section of coast, foreshore exposures of mudstones are largely limited to brief periods of storm removal of beach sediment and exposures are largely limited to very low spring tides. Rapid erosion is caused by a combination of removal of soft mudstone by marine erosion, and landslides of higher horizons. Removal of fossiliferous rock thus occurs as direct erosion by waves at the cliff base and foreshore and of landslipped higher units at beach level before rapid erosion of the slipped material. In both cases, there is some concentration of fossils loose on the beach (especially dense, pyritic specimens) before their final destruction. Net erosion rates are high, but extremely episodic, with the majority of loss of cliff volume occurring during brief periods of extreme weather and large tides.

The beaches and cliff base are visited by very large numbers of people each year, but much of the potential loss of fossils occurs during autumn and winter storms when casual visitors/collectors are largely absent. Rescue and collection of significant fossils occurs largely during these times, when weather conditions are typically poor. It requires highly skilled and dedicated people to be on the beach collecting during these brief periods of rapid erosion. As a result, very few finds of larger fossils are made by casual collectors or academic palaeontologists, who lack the opportunity (or willingness) to be on the beach during extreme weather and tide events. Whilst many significant fossils are found by enthusiasts, the majority are recovered by professional, commercial, collectors. In the Charmouth area, commercial collectors are largely local and are therefore able to be on the beach at short notice, and also have developed the skills required to extract large fossils, such as vertebrate skeletons, very rapidly (typically within a single tide) and within extreme conditions. The area local to Charmouth supports several professional fossil collectors who make a significant proportion of their income from local fossils. Vertebrate skeletons are relatively rare and as such are not a reliable source of income, whereas ammonites are abundant and often spectacularly preserved in coloured calcite. Ammonites are clearly important, but the majority of commercially-collected specimens comprise a small number of species, most of which are well represented in museum collections and cannot be regarded as scientifically significant.

Upon establishment of World Heritage Site status, a system of recording of significant finds was established (Larwood 2001, 2007; Townley and Larwood 2012). This system provides a mechanism for all major finds to be recorded, and allows museums or other research organisations a chance to purchase commercially collected material. It has been stated (Page 2006) that many specimens were not recorded, but this was based on a comparison with an inland site yielding a rather different fauna and so these criticisms are best regarded as invalid (Sole 2007). Whilst there clearly is the potential for non-reporting of specimens, and uncertainty as to what constitutes a significant fossil, the system appears to work extremely well.

The Charmouth coast represents an example of a site that demonstrably benefits from uncontrolled, but recorded, fossil collecting. The scientifically important fauna only exists due to collecting, and the nature of the erosion of the site necessitates commercial as well as other forms of collecting. Indeed, despite the intense collecting that currently exists, the presence of water-worn fragments of large vertebrate bones on the beach suggests that despite this, skeletons are still lost to erosion.

Coast with moderate erosion; Kimmeridge Bay, Jurassic Coast World Heritage Site, UK.

Towards the eastern end of the Jurassic Coast World Heritage Site is Kimmeridge Bay. This area exposes mudstones and thin dolomitised limestones of Late Jurassic (Kimmeridgian and Tithonian) age. While the fauna of abundant ammonites, fish and marine reptiles is broadly similar to that of Charmouth, the nature of the exposures is rather different. The mudstones are hard and fissile, and are exposed in relatively low vertical cliffs and very extensive foreshore ledges. Erosion is far slower than at Charmouth, comprising both rockfalls from the cliffs and gradual marine erosion of the ledges. Erosion is also less episodic than at Charmouth, and large expanses of the foreshore ledges are only accessible on exceptionally low tides. It is often only after storms that the rock is not obscured by marine algae or beach sediment. Kimmeridge Bay is visited by large numbers of geologists as well as tourists, but palaeontology is

generally of secondary interest to geologists, with much research being focussed on the sedimentology of this important hydrocarbon source rock. Despite being frequently visited, Kimmeridge Bay is more remote than Charmouth, with no large towns nearby, so few people are on site to take advantage of new exposure as it becomes available. In addition, the preservation of ammonites as crushed and flattened films on the mudstone rather than three dimensional within nodules does not lend them to commercial collection. Consequently, commercial collecting has been very limited.

Reptiles have been recorded since the 19th Century (e.g. Hulke 1871, Mansel-Pleydell 1888) but these have generally been isolated finds. While occasional finds have continued (e.g. *Kimmerosaurus* Brown 1981), *in situ* fossils have been few in number and many of the vertebrate fossils from the region have comprised isolated loose large bones collected from the sea floor by scallop divers. This situation changed in the late 20th Century when a local collector, Mr Steve Etches, started to amass a large collection, including many previously unknown vertebrates, from Kimmeridge Bay and the surrounding area. Living close to the site and having ready access to exposures, a single dedicated collector was able to collect more significant fossils within three decades than the total diversity collected by all other people combined over the preceding 150 years. In 2016, a Heritage Lottery Fund funded museum, The Etches Collection, was opened in Kimmeridge Village to house the collection. This museum allows the fossils to be available for research and provides an important local source of tourist revenue as well as providing a local community hub. Whilst unfounded criticisms were previously raised about the unavailability of fossils in a private collection to research, it could be argued that having all of the specimens available in a single site now benefits the community and provides a learning resource local to the original fossil site. Given the particular circumstances of the site, we consider that the situation in Kimmeridge Bay could be regarded as a superb example of the benefits that a non-professional collector can provide, and the impact that a single dedicated person can have on palaeontology. A ban on fossil collecting would have prevented the Etches Collection from ever existing.

Very slowly ablating remote desert; Fayum, Egypt.

The fossiliferous parts of the Fayum area of Egypt, west of Cairo, cover a large area of stony desert to the north and west of Birket Qarun Lake. Rocks comprise shallow to marginal marine Late Eocene units overlain by fluvial Early Oligocene. The area is very arid and has virtually no vegetation or modern soil cover. The topography comprises small escarpments and large areas of intervening flat, bedding-parallel desert floor. Whilst some of the flat areas have exposure or near exposure, with rock below a veneer of desert sand, much has a more extensive cover of regolith, Holocene lake margin sediments and, in places, dune sand. Several archaeological sites are present in the eastern part of the region. Erosion is very slow, as evidenced by the good preservation of archaeological sites. Wind ablation is probably largely limited to areas close to Birket Qarun where dune sand is present. Erosion of higher parts of the area is probably largely restricted to physical weathering by heating and cooling, and rapid erosion during rare but violent precipitation events. Net destruction of rocks and fossils is consistently very slow. Fossil vertebrates have been known from both the Eocene and Oligocene units since the expedition of Schweinfurth in 1886, but study has been discontinuous and the remoteness of the area has necessitated that fieldwork take the form of extensive expeditions. There is robust legal protection for fossils in the area, with the legislation appearing to be a variant on the protection and conservation legislation that has been applied to archaeological material.

Early expeditions in the early 20th Century focussed on larger fossils, especially Oligocene mammals. A resurgence of interest in the latest 20th and earliest 21st Century has focussed more on Eocene cetaceans (mostly at Wadi el-Hitan; see below) and Eocene and Oligocene non-marine mammals, in particular primates (e.g. Simons 2008). Early exploration involved extensive surveys of the flat areas, with development of some particularly bone-rich quarries in addition to excavation of individual specimens. More recent study has involved less exploration, consisted largely of areas previously surveyed in the eastern parts of the region, and has concentrated more on development of particularly fossil-rich sites, with extensive use of sieving, such as at the well-known site BQ-2.

Although many fossils have been collected over the decades, vertebrate fossils are still abundant in the field. It is unclear which of these are specimens that have been seen previously and not collected, or have not previously been recognised. Some almost certainly fall in the former category; as an example a small cetacean skull is well exposed and conspicuous on a ledge on the top of the hill referred to as "Zeuglodonberg" by Dames (1894) (*Zeuglodon* being a generic name previously applied to many early cetaceans). Considering the large area of exposure in the Fayum and the relatively small number of

expeditions, it is probable that large proportions of the area have not been adequately surveyed, whilst the time since the initial expeditions will probably have allowed exposed fossils to have been destroyed and new ones to become exposed. In addition, there is no evidence that large areas at the western part of the area have even been systematically surveyed for fossils. Brief visits to this region revealed abundant cetacean and other vertebrate fossils within the Eocene parts of the succession (CJU and DJW personal observation).

The low frequency of exploration and slow rates of destruction of the rocks and fossils of the Fayum suggest that while many larger fossils have been discovered, others are likely to have been destroyed. Despite this, the very extensive exposure yields many fossils to interested researchers, and fossils may be regarded as an effectively unlimited resource. Within this setting, the small number of known non-marine microvertebrate sites may be regarded as sensitive sites of extensive interest. Even though fossils have strong legal protection, the full locality details of some of these sites, such as the famous mammal site BQ-2, have never been published, presumably to protect them from unauthorised collection. In contrast, marine microvertebrates are widespread in the Eocene parts of the succession (CJU and DJW personal observation) and have never been sampled to any extent. We therefore consider that the conservation status of the Fayum has allowed for extensive discoveries to have been made, and there is great potential for further discovery in poorly explored areas or amongst poorly known microvertebrate assemblages.

Despite the fact that the conservation criteria for this region are unlikely change in the future, there are changing impacts on the site that may influence its conservation. The completion of a road along the north side of Birket Qarun has allowed far easier access to the area. There has been a suggestion that major development was planned for the northwest shore of Birket Qarun. This would destroy exposures rich in fossils, including cetacean skeletons; rescue excavations would be needed, but this might require changes in the conservation laws. There have also been some cases of fossils being lost due to illegal activity. After political upheaval in 2010, illegal excavation of antiquities became widespread in Egypt. Whilst there is no evidence of illegal excavation of fossils, we know of at least one case of fossil destruction with a cetacean skeleton being destroyed when a pit was dug through it. A likely explanation is that palaeontologists were observed studying the skeleton and, thinking that archaeological material was the source of the interest, local people dug the site looking for antiquities, inadvertently destroying the skeleton.

Very slowly ablating accessible desert; Wadi-Al Hitan World Heritage Site, Egypt.

At the southwestern extremity of the Fayum is the UNESCO World Heritage Site of Wadi Al-Hitan. Originally far less accessible than the rest of the Fayum area, the extreme concentration of cetacean skeletons and other fossils, along with dramatic scenery, saw this site developed for tourism and an access road constructed. One reason that this protected status was requested was that a number of bones had been removed from skeletons by visitors (Gingerich pers. comm.) The area close to the access point has been developed with paths, and fossils are presented both in the open and within an on-site museum. The public area of the site is within shallow marine Eocene sandstones, but the north and north-eastern parts of the World Heritage Site fall outside the public area and have exposures of deeper marine facies and overlying marginal marine rocks. Within the public area, several partial cetacean skeletons are exposed either *in situ*, or on the desert surface, where they have been removed from rock by erosion. In addition, some specimens have been excavated and exhibited close to their site of discovery. The specimens on display in the public area are spectacular, but typically incomplete and/or poorly preserved examples of well-known species, and thus of relatively low scientific value. Some better preserved specimens have been excavated and studied, and are now present in a museum at the entrance to the public area. As in the rest of the Fayum, erosion rates are very low, and many of the specimens are strongly mineralised and resistant to damage. There are, however, exceptions; a rostrum of the sawfish *Pristis* beside one of the paths was relatively complete in 2008, but by 2012 had been reduced to weathered shards. There is also evidence that some damage may have been done by visitors; a rostrum of *Propristis*, which originally had rostral denticles (probably from elsewhere) placed alongside it, had none of these in 2009, they presumably having been stolen. Most of the larger specimens excavated from this area were removed before World Heritage Site status was given, but some specimens, now in the site museum, were collected after this time. In addition to large tetrapods, small and microvertebrates, especially shark and ray teeth, are well represented (Underwood *et al.* 2010). Some of these were collected in 2008-11 by both surface collecting and sieving, in each case aiming to collect away from paths. Outside the public area, large areas of exposure yield fossils ranging from microvertebrates to cetacean

and other tetrapod skeletons. Excavation of a number of the latter has taken place, but a large proportion have been logged and left *in situ*. It is evident that even in this region, some areas of exposure in the northeast remain to be surveyed in detail for large vertebrates, let alone smaller fossils.

Wadi Al-Hitan thus represents a site where visitor numbers have gone from very low to high with the influx of tourists (though current numbers have collapsed due to safety concerns). Fossils left *in situ* are of great educational benefit, whilst those removed have been able to be a focus of scientific study and are now also visible, even if as a result there are less fossils to be seen in the field. Outside the public area, there is still great potential for new finds, including cetaceans within the oldest parts of the succession, and non-marine vertebrates within the uppermost parts. Marine small and microvertebrates and some (typically non-aragonitic) invertebrates are abundant and diverse throughout the succession. The legal protection for fossils in Egypt is very much geared towards large fossils, where individual specimens can be documented. The legal protection status of small fossils, and particularly microvertebrates and other mesofossils is less clear, as a sieved residue of fossil-rich sand is collected in the field, rather than individual fossils.

Artificially-maintained inland site; Abbey Wood, UK.

The conservation of the palaeontological site at Abbey Wood, SE London, offers an example of how non-professional and academic palaeontologists, as well as the general public, can work together to maximise the utility of a small, sensitive site. The presence of shells and sharks' teeth coming out of rabbit burrows was first published by Whitaker (1872: 254). Following this discovery, the woodland was surveyed, with fossil collections being made in the 1920s by two local amateur naturalists F. J. Epps and St. J. Marriott (Marriott, 1925) and the significance of the site became apparent. The vertebrate fossils, mainly fish, were published by White (1931). Subsequent work at the site has yielded a considerable number of tetrapods, especially mammals.

The site at Abbey Wood comprises a small excavation where exposure is only available during temporary digs, with the site being backfilled for reasons of safety for the majority of the time, due to its position within a public park. The rocks comprise an unlithified shelly sandstone lens of basal Eocene age, containing very abundant fossils. It represents an estuarine facies which contains a unique biota, dominated by shallow water marine organisms with some transported terrestrial elements. The fauna is dominated by a very rich, but low diversity, assemblage of gastropods, bivalves and chondrichthyan teeth, and a number of holotypes of these groups have been sourced from this site (White, 1931; Frost in White, 1931; Wrigley in White, 1931; Stinton, 1965). In addition, there are examples of a number of other groups, with the remains of terrestrial mammals being of special interest and being the focus of a number of scientific papers. Since 1975 Abbey Wood has been a Site of Special Scientific Interest (SSSI) for its palaeontology (e.g. Cooper, 1932; Kühne, 1969, Walker and Moody 1974 and Hooker, 2010), but also sits within a woodland that is itself a botanical SSSI. The locality is in a well-used wood within the outskirts of London, which is itself heavily visited for recreation.

Prior to the 1970s, with permission of the park authorities, deep excavations into the shell bed were relatively uncontrolled. Once the site was designated as a geological SSSI, access to the *in situ* shell bed was regulated by Natural England and its predecessors. Excavation was only permitted for recognised organisations, generally museums, universities and geological societies. Currently the site remains unexposed for most of the year, but there are annual excavations undertaken by the Tertiary Research Group in collaboration with the Natural History Museum, London. Excavations require use of a mechanical digger, the costs of which are met by a combination of grants, TRG funds and by donations from private collectors. The fossil-bearing sediment is excavated and made available for sieving by those present. In general, non-professionals attending the excavations can keep all of the material they collect via sieving the shelly sands other than the rare tetrapod remains, which go to the Natural History Museum, London. All sediment has to be sieved down to a mesh size of 500 microns, so that small and significant mammal teeth are not accidentally discarded. As space is limited, the numbers sieving cannot exceed 40 people. The shell bed is wet sieved with the coarse fractions sorted in the field and the fine, generally less than 10mm, sorted at home. Researchers who have a legitimate need to see the deposit *in situ*, or wish to collect elements of the fauna, are directed by Natural England to contact the excavation organisers. Those who wish to study the material, but not necessarily collect it, are directed to the Natural History Museum, London, or the private collection of one of the regular collectors.

In addition to sieving on site, large amounts of sediment are removed for sieving elsewhere. This is dried and larger shells and pebbles are removed, along with any larger bones. Some of this (approxi-

mately 350 kg per year) is taken to the Lyme Regis Fossil Festival where it is used in a closely supervised sieving and fossil collection/identification exercise for children, who are similarly allowed to keep the (non-tetrapod) fossils that they find. During the rest of the year, large numbers of individuals and school parties visit the site and search the surface spoil left by recent and historical diggings to find shells and sharks' teeth. Over the 12 years until now, we estimate that about 6,500 childrens' sieving exercises have been performed at Lyme Regis fossil fair and elsewhere.

We therefore consider that this small and potentially very sensitive site has shown how thoughtful management has enabled a considerable range of people to benefit from the fossils present, and that by using material from this site for outreach, large quantities of material is searched for fossils, greatly increasing the probability of recovering rare and important specimens, most coming from bulk sampling for mesofossils.

Recommendations for best practice.

Fossils in the field, and the fossiliferous rocks within which they occur, are a valuable resource for many different interest groups, of which sadly only academic palaeontologists usually get considered when best practice is discussed. Consequently, whenever legal protection is given to fossils, it is commonly only with academic palaeontologists of the country in question in mind. Ultimately, this allows the construction of legal frameworks that are often at best inflexible as far as optimal utilisation of palaeontological resources are concerned, and at worst restrict more or even all interested parties from accessing fossils. The ultimate end point of many laws striving to protect fossils thus is that fossils are destroyed and are lost to not only science but all other interested parties.

We would like to suggest that the conservation and protection of palaeontological resources should include a far greater degree of pragmatism and take into account the rate of exposure and destruction of the rock and fossils, type and size of fossils present and the frequency of visits by interested parties. Whilst it is not expected that it would be possible to use these variables in constructing a legal framework or even rigid code of conduct, these should inform any decisions made. We consider that as long as an overriding principle that a fossil collected is more useful to someone than one destroyed is maintained, that fossils of scientific importance should be placed in the most appropriate museum(s), all data associated with a fossil should be made available to allow reproducibility of science and that no one should have the right to damage a site to render it unusable to other interested parties, little other detail should be needed in any code of practice.

Whilst we do not aim here, to challenge laws regarding fossils, we would suggest that some are unfit for purpose and ideally a more pragmatic approach could improve their utility. One regularly discussed example is the influence of laws covering Brazilian fossils, in particular in respect to the vertebrates from the Santana and Crato formations. Besterman (2001) argues that these laws should be adhered to; we do not deny this, only that the laws are unsuitable. Martill (2001) notes that at the time of writing that a ban on fossil export was frequently ignored and many fossils left the country, but, because these were illegal, they were tehnically not available for research. Subsequently, more stringent application of fossil export laws has stopped the excavation and trade in these fossils. This has dried up the supply of fossils, both common and rare, and we are unaware of any scientific papers based on specimens collected subsequent to these laws being rigorously applied. Thus, the application of laws has prevented rare and important fossils being discovered and all potential beneficiaries, including those in Brazil, have been denied potentially important material.

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