# AN ALTERNATIVE SHELVING ARRANGEMENT FOR NATURAL HISTORY COLLECTION OBJECTS TO OPTIMIZE SPACE AND TASK EFFICIENCY

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*Abstract.*—A taxonomic and alphabetic arrangement (TAA) of objects on shelves has prevailed in fluid-preserved natural history collections while they were managed by scientists for their own research. Now most collections are databased and internet-accessible to facilitate very different forms of research accomplished remotely by researchers who require less physical access to specimens. The collections staff who make those data available struggle to manage collection growth with limited space and budgets, while demands on them are increasing, necessitating task and space-efficient collection management solutions. We describe an alternative arrangement of objects based on their size and catalog number (OCA) that capitalizes on modern databases. Our partial implementation of this system facilitated pragmatic between-system comparisons of space use and staff time required for routine tasks. Our OCA allows 17% more jars to be stored in a given space than a TAA (not counting spaces left for growth), but adjusting vertical spacing of shelves could increase that to 115%. Ten of 15 staff tasks were more efficiently accomplished in the OCA section of the collection, and we propose ways to improve efficiency for three of the four tasks for which the TAA outperformed the OCA.

*Key words.*—fluid collection, space, efficiency, object arrangement, preventive conservation.

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## Introduction

Natural history collections are rooted in traditions dating back to the 1600s, when biologists first figured out how to preserve organisms and store them for long periods of time (Simmons 2014, 2016). Collections were growing quickly by the 1800s (Global Biodiversity Information Facility 2020), and specimens became the basis for formally naming species before becoming critically important for study of evolution, ecology, biogeography, and conservation (Graham et al. 2004, McLean et al. 2016). Collections have continued to grow, with specimens collected at many more locations and through modern times, resulting in a vast globally distributed body of specimens representing most of the known diversity of life on Earth over the last 400 years (Global Biodiversity Information Facility 2020).

Modern technologies (e.g., DNA analyses, high-resolution CT scanning, and chemistry) have improved our ability to use collections for knowledge advancement, and databases and the internet have revolutionized how specimen data (e.g., collectors, collection date, and locality) are managed, archived, and used. Conversion of hand-written museum catalogs to digital databases made available by global biodiversity data aggregators in a standardized format enabled open sharing of formerly obscure specimen-based data. These data are being used in new ways (Chapman 2005), often by powerful computers. Over the last 20 years ecologists and researchers in other disciplines have become major users of such data to provide insights into how the world's ecosystems work, how they have changed, and how they might be conserved (Hendrickson and Labay 2014, Rodrigues 2018, Tarli et al. 2018, Ball-Damerow et al. 2019, Girardello et al. 2019, Lang et al. 2019).

However, the way these now more-valuable-than-ever collections of specimens are stored has hardly changed over the centuries. Environmental conditions in specimen storage spaces have improved (Simmons 2014), and databases have improved greatly, but the traditional method of arranging specimens with specimens of the same species placed near related species is deeply rooted and almost universally accepted. The University of Texas (UT) Ichthyology Collection (Hendrickson et al. 2020) has used this taxonomic arrangement since inception, but as the collection grew and space became increasingly limited, we began to see this classical arrangement as unviable.

### *Traditional Taxonomic Alphabetical Arrangement (TAA) of Objects*

Just as librarians use the Dewey Decimal Classification system and other systems to cluster books by subjects, scientists have long shelved specimens in a system that reflects their morphological similarity or relatedness. In the 1700s Linnaeus developed his system of binomial nomenclature and used it for shelving his specimens (Sanders 1997, Müller-Wille 2006), and this system is still used for natural history collections worldwide. Because the primary purpose of specimens over most of that long period was for describing species, and because most research focused on relatively narrow taxonomic groups, this system allowed specialists to easily browse a small area of the collection that contained all specimens of interest.

Most fluid collections still arrange their jarred specimens in some taxonomic order, typically alphabetically at the lower taxonomic levels (genus and species) and sometimes alphabetically at higher levels (TAA; Simmons 2013, 2015a; Huber et al. 2016). But, as a rule, at the lower taxonomic levels all specimens of a species are clustered on shelves adjacent to clusters of other closely related species. Within each species, containers are usually arranged by catalog number and/or geography (e.g., political jurisdictions or drainage basin). In these systems, empty shelf space is always necessary between species to allow for growth and coshelving of variably sized jars results in less-than-optimal utilization of shelf space (Fig. 1). When a small jar shares a row with a larger jar, unused space exists on either side of the smaller jar. Also, unused space can occur at the end of rows of jars where there is insufficient space for the next jar in the sequence. Recently, John E. Simmons, long a prolific writer on collections practices, has been critical of the traditional system, arguing for a better system not subject to changing taxonomies which uses space more efficiently (Simmons 2013, 2015a, 2015b).

### *Problem*

A quick review of the history of UT fish collection is necessary. The basic TAA implemented with the collection's creation in 1950 accommodated growth for 70 years and persisted through at least three moves into progressively larger spaces. The last move 27 years ago filled our new space to 40% capacity with the ~12,000 lots in the collection at the time. There are now >70,000 lots in the collection, which has grown more in the last two decades than in the five decades prior (Fig. 2). In general, the TAA served us well when we had ample space, but as we outgrew each collection facility, inefficiencies of this standard system became obvious. Spaces for growth were so small that creating space for a single new species could require shuffling thousands of jars over sometimes as much as 30 m of shelving. With a larger facility looking very unlikely, we were forced to deal with the problem within the constraints of our current space and budget.

We ended up dedicating substantial effort to tasks that we never would have considered had we not been space-limited. We began by laboriously rehousing inefficiently stored specimens. Small specimens in larger-than-necessary jars were placed in vials that were then cohoused in multiple-lot jars (e.g., up to 30 vials/0.9 L jar), and larger specimens were moved

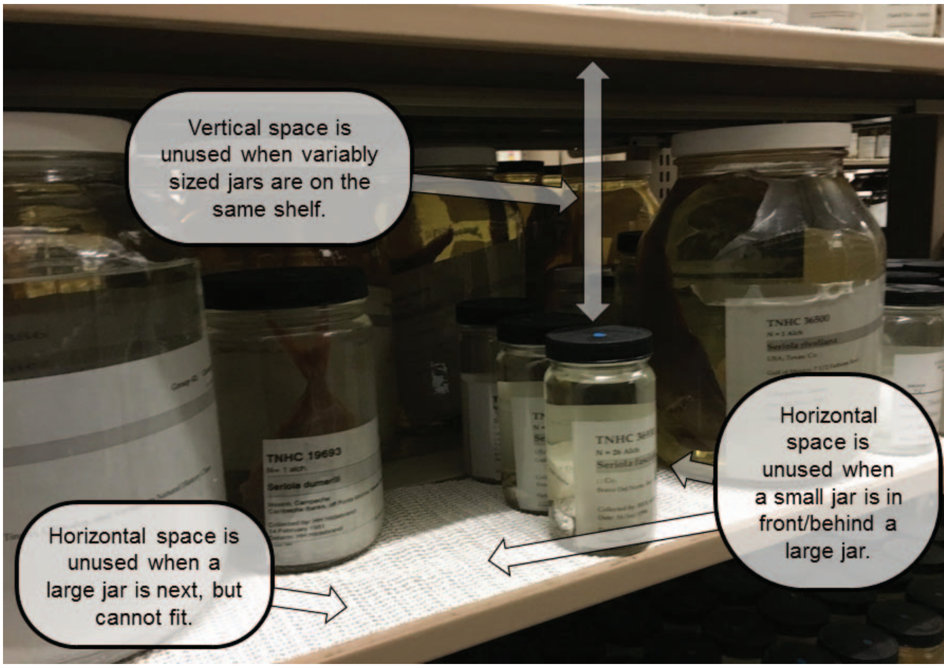


Figure 1. Taxonomically arranged shelf illustrating the unused horizontal and vertical space inherent in systems that comingle jars of multiple sizes on single shelves.

from jars into multi-lot tanks (e.g., 65 larger specimens/132 L tank). Each rehousing required at least some relabeling and database editing, and this move of 5,352 lots (8% of the total collection) to multi-lot containers freed ~30 $m^2$ of shelf area (8% of total). Next, we freed up ~50 $m^2$ of shelf area (14% of total) by moving ~5,800 lots to a secondary

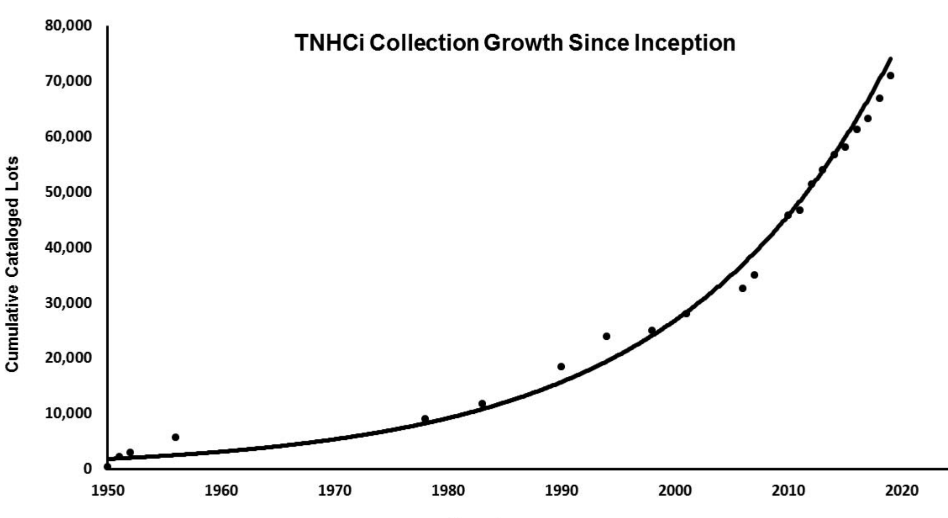


Figure 2. Cumulative growth history of the Texas Natural History Collections fish collection (TNHCi).

storage facility ~0.8 km from our primary collection building. Unfortunately, that facility has poor environmental controls and frequent maintenance issues, but we had no better solution. Finally, ~8 $m^2$ of shelf area (2% of total) was liberated by packing ~3,000 of the smallest jars (0.2 L) of our most common species into high-density boxes and stacking them on dollies in aisles.

Those efforts helped with our space issue, freeing up ~30% of our shelf space. But it came with a high cost in terms of staff time invested, and we soon began to notice incidental collateral impacts stemming from those efforts. Collection management is now complicated by fragmentation. Specimens of virtually every species are now in at least two, and more often three, different places. Housing specimens in separate buildings doubled or tripled the equipment and effort required for monitoring environmental conditions and coordinating maintenance, and increased the cost of purchasing supplies such as spill kits, extra jars, ethanol, broken glass disposal containers, step ladders, and so on. Not only did creation of multi-lot containers take considerable time, it almost surely generated new databasing/labeling errors and loss of original jar labels that didn't fit into vials. Specimen retrieval and reshelving is now more time consuming, and multi-lot tanks now clog aisles and hallways. While we succeeded in saving shelf space in our primary collections area, the overall workloads of collection workers have increased. Still battling a shortage of space, growing at our fastest-ever rate, and confident that additional shelf space will not become available for some time, we concluded that we needed to be more creative about how we function in the space available. Given that the only new space for collection growth was distributed across hundreds of hard-to-use small spaces between species, we decided we had little option but shift all jars to coalesce all empty space to the end of the range.

### *New Solutions (Inspiration from the Harvard Model)*

The UT fluid-preserved collections space adjoins the university's High Density Library Storage Facility (University of Texas 2020). While the library facility is administratively distant and stores much larger collections of different objects in different ways, we began to realize we have much in common. The library's mission is to provide densely packed and long-term preservation of library materials "in a highly controlled environment with optimal preservation conditions, coupled with a retrieval process to get items back into the hands of users should they be needed." Simply replacing "library materials" with "biodiversity specimens" results in essentially our mission. The lifespan of the objects (and thus the storage systems) are also comparable—they estimate their paper objects will be in good condition 200–300 years in the future, while fluid-preserved specimens are expected to persist for at least that long (Simmons 2014, 2018).

Perhaps the biggest difference is that, over the last 27 years, our collection space allocation has not changed, but the library facility has tripled by addition of two expansion modules, and another was just funded. At the same time, Library Storage evolved into a multi-institutional repository, housing items from both our university and Texas A&M University, and it has diversified beyond libraries to include (dry) objects from campus museums. The library has the advantage that almost everyone acknowledges the importance of books, but few recognize the importance of dead fish in alcohol, and the library has obviously been far more successful at demonstrating growth and space needs to administrators. But, like them, we now find ourselves hoping to deviate from long-standing traditions. The library uses the Harvard Model of spatial organization (Weeks and Chepesiuk 2003), which has been referred to as "an almost profane violation of standard library organizational protocols," but which ensures "the most efficient

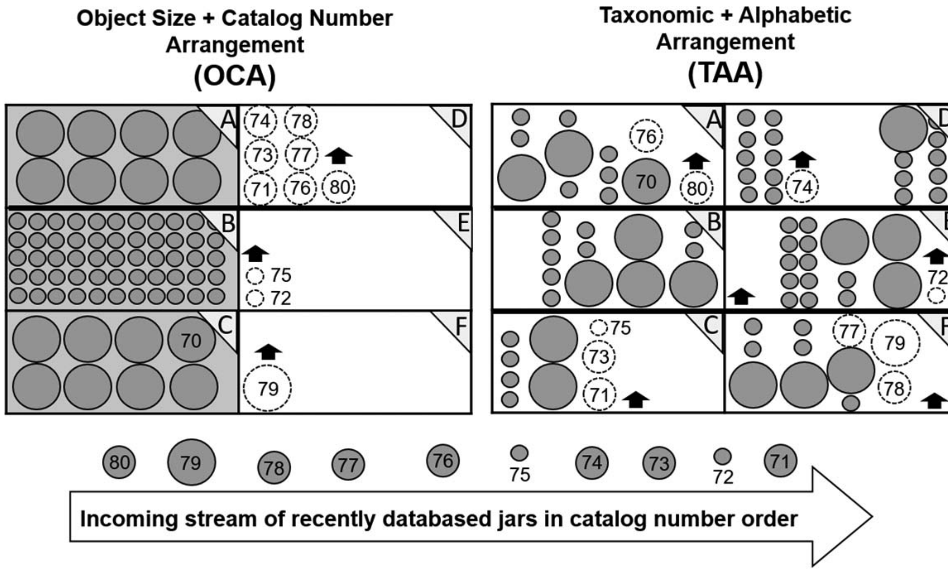


Figure 3. Comparison of the OCA and TAA systems using 80 jars and three jar sizes (three is typical for many collections, though some have more). Each shelf, labeled alphabetically, is viewed from above and marked in gray if full. The 10 most recently cataloged jars are numbered, and white circles indicate their shelving locations. Under the OCA, growth occurs at three locations (one for each jar size), whereas under the TAA growth occurs at many locations (six here; one for each species).

application of available space" by using object size as the primary determinant of location (University of Texas Libraries 2018). Some librarians worry that the system is basically unusable by humans without access to a database, but it continues to be used successfully by both its creators and now at least 75 other high-density facilities operating across North America (Payne 2014).

### *Object Size– and Catalog Number–Ordered Arrangement (OCA) of Jars*

Influenced by the library's Harvard Model, the object size– and catalog number–ordered arrangement (OCA) we developed and tested eliminates growth spaces around each species and disregards taxonomy. It can be best understood if described from a workflow perspective. Variably sized jars move from the cataloger to the shelver on a cart in catalog number order. One at a time, in order, each jar's size is considered by the shelver, who places them on one of three shelves (one for each jar size), where there is space for growth. If a shelf is full, the next jar goes on the next empty shelf and defines that shelf's jar size type (Fig. 3), such that:

- Jar size and catalog numbers both determine how jars are arranged on shelves. Jar size determines shelf, and catalog number determines order of jars on the shelf.
- Jar size defines shelf types. Since we have three sizes of jars (0.2 L, 0.9 L, 3.8 L) we have three types of shelves. Collections with many jar sizes might have more shelf types and/or lump jars into size categories (resulting in at least some space inefficiency).
- Shelves become defined by jar size when their first jar is received, which depends entirely on the incoming stream of cataloged jars.

Figure 4. Compactly shelved jars in our OCA system. Little space (other than vertical) is unused. In our implementation (as in our TAA), jars are precariously close to the edges of the shelves. We plan to install guard lines that will prevent jars from falling.

- Growth occurs simultaneously on each jar-size shelf (three size categories, so three locations of growth).
- Jars of the same size are coshelved, and because all jars on any shelf are of the same size, all shelves of the same type hold exactly the same number of jars.
- Since both are consolidated, empty and full spaces are fully visible and easily quantifiable by anyone (including administrators on tours).
- Shelves are filled sequentially from one end of the range to another, so that all empty space in the range is at one end and all full space at the other. The continuous empty space can be used as surge space or for organizing incoming specimens.

Once shelved, we envision no need to ever move jars to different positions. If any are removed, the absence is obvious, and the jar will return to the void left by its removal. Thus, every jar can be assigned a permanent "address," that could, if desired, be databased. Lacking an address, locating a jar requires knowledge of both its size and catalog number, and our database has that information. In case the jar size is not documented in our catalog, with only three jar sizes, any jar is still quickly found on the three possible shelves. Figure 4 illustrates the spatial efficiency gained by our current OCA system.

## Methods

Our collection is actively growing, making it a good test for a comparative assessment of the TAA and OCA. During 2010–2018 we annually added on average 2,600 lots via

36 accessions (deposits). At the same time, loans averaged 13 and visiting researchers averaged eight. Because it is the home of the Fishes of Texas project (Hendrickson and Cohen 2015), our team (averaging eight staff) uses the collection regularly by extracting, examining (mostly for species determination, or original label-based information verification), and reshelving specimens. We also photograph ~300 lots per year (2010–2018).

Following all of the collection compression efforts described previously, in February of 2014, about six years before this writing, we began a roughly 11-month-long effort to compress the majority of our TAA collection to allow for continued growth. We shifted jars to eliminate almost all gaps left between species for growth, realizing that this TAA section with ~44,200 lots occupying 567 shelves (256 $m^2$ of shelf surface) could then no longer grow. That opened up 371 empty shelves (167 $m^2$ of shelf surface, in which we implemented the OCA system with newly cataloged specimens. Currently the OCA section has 238 shelves (100 $m^2$ of shelf surface) filled to capacity (16,374 lots).

To compare jar-packing efficiency we counted jars from 21 $m^2$ of shelf space in the TAA section (now lacking growth spaces) and 100 $m^2$ of shelving in the OCA. Per-shelf jar counts in the TAA are highly variable and subject to bias by shelf selection. For example, some taxonomic groups are dominated by small-sized individuals and more likely to have smaller jars, which increases counts. We sampled a large selection from both arrangements, selecting areas of the collection that we thought were representative of the collection as a whole. To qualitatively compare efficiency of performance of common collections tasks carried out in both arrangements, we focused on 15 tasks that entailed finding, moving, splitting, and combining jars.

## Results and Discussion

### *Jar-Packing Efficiency*

The OCA holds, on average, 164 jars/$m^2$ of shelf space versus 140 jars/$m^2$ in the TAA (17% more), not counting spaces left for growth, which were removed. The collection's original 367 $m^2$ of shelf space could hold 8,808 more jars using the OCA instead of the TAA. At our fastest growth rate, that would allow growth for another 3.4 years. But, a TAA cannot operate without interspecies growth spaces, and if those spaces are set at a moderate 30% of the collection, the density in the TAA drops to 98 jars/$m^2$, translating to 67% more jars/$m^2$ under the OCA.

The TAA section is perhaps unusual with regard to its density due to our extensive manual efforts to fit it into less space, as described earlier. Moving specimens out of larger jars into tanks and from smaller jars into multilot jars had the effect of removing many of the largest and smallest jars, making the collection more densely packed than if we had not undertaken those efforts. It is thus not unreasonable to expect that a TAA collection that has not already experienced space savings efforts similar to ours will be less densely packed and therefore compress even more by conversion to an OCA.

The improvement we achieved by converting to the OCA could be increased by adjusting vertical shelf spacing to match the height of the jars. Doing so to the maximum extent would require pull-out drawers to allow access to jars, but partial vertical compression without drawers would still increase space efficiency and might be more practical. Figure 5 summarizes our comparisons of various combinations of vertical and horizontal compaction of both TAA and OCA. We calculated that a 207 $m^3$ collection space, organized with an OCA and using shelves equally spaced for the tallest jars, can hold 41,837 jars, but with full vertical compression could potentially hold 76,861 jars (84% more). A vertically

Number of Jars Fitting into a 207m³ Fixed Space Using OCA and TAA Senarios

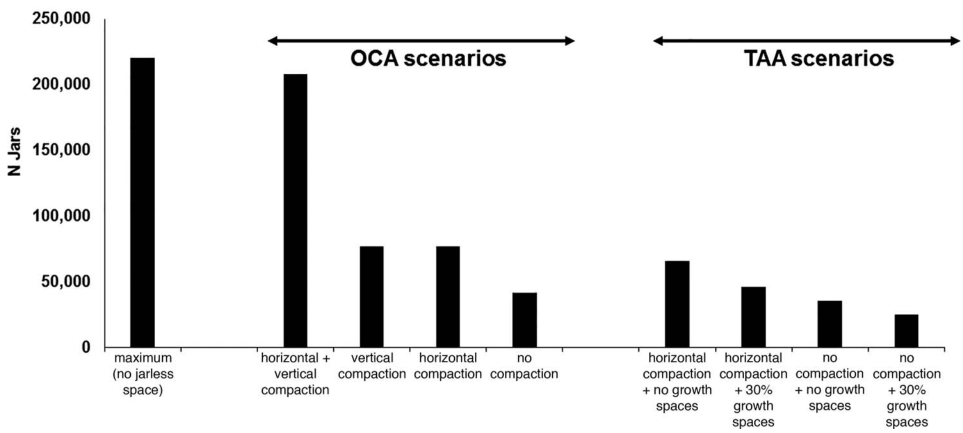


Figure 5. Modeled total number of jars that could be stored under different space utilization scenarios within the fixed volume of one of our collection spaces, using our own collection's proportions of jar sizes (85% 0.2 L; 12% 0.9 L; and 3% 3.8 L). On the left is the theoretical maximum number of jars in the space if packed wall-to-wall and floor-to-ceiling without shelves or aisles. Horizontal compaction refers to the use of mobile shelving units on rollers, allowing all but one 1 m aisle to be replaced with shelving. Vertical compaction can only be employed in the OCA if all jars on each shelf are the same height allowing installation of shelves to minimize space above all jars.

compressed OCA would allow storage of 41,040 more (115%) jars than a TAA with equally spaced shelves (all at the height of tallest jars, the only option for a TAA).

Horizontal compactors are a common and effective space savings measure because they can nearly double shelving area. But, expanding and contracting aisles to allow access to specimens takes time and reduces shelving efficiency, especially so in growing TAAs, where growth occurs across many aisles (one aisle in an OCA). But our calculations demonstrate that vertical and horizontal compaction of an OCA were similar in terms of jar density. Collections could get nearly the same space savings by converting to an OCA and implementing the much less expensive and more task-efficient option of installing additional shelves to existing shelving units versus installing compactors.

If both vertical compaction and horizontal compaction were implemented in an OCA, the jars would be packed near the theoretical maximum number of jars for the space—with unused space attributed to little more than a movable aisle and shelving structure. However, this was a thought exercise that did not attempt to account for empty spaces required for fire safety, ventilation, and so on. Also, these numbers are, of course, collection specific and depend on the ratio of jars of different sizes. For this exercise, we used the ratios in our collection (85% 0.2 L; 12% 0.9 L; and 3% 3.8 L).

## *Task Efficiency*

Results of our qualitative assessment of collections task efficiency and accuracy are in Table 1. In 10 of the 15 activities evaluated, the OCA outperformed the TAA. The TAA performed better than the OCA on four tasks, and for one task we could not determine a difference.

Table 1. Activities that occur frequently in the Texas Natural History Collection (TNHCi) with qualitative evaluation of how the shelving systems affect them. Boldface indicates which system is more efficient in our experience.

| | Taxonomic alphabetical arrangement (TAA; with spaces for growth) | Object size and catalog number arrangement (OCA) |
|---|---|---|
| Initial shelving of incoming specimens | Slower and more error prone: Workers must find the location among hundreds or perhaps thousands of locations where growth is occurring (one location for each species); if space is not available, jars must be rearranged to make space; ladders and other supplies may need to be moved throughout the range; workers get confused by similar or synonymized names; when space is not available, workers may take shortcuts leading to errors | **Faster and less error prone: Workers place jars at the end of the last shelf for each of the three jar sizes; there are only a few locations where the collection is growing, and they are usually very near each other; a single shelving station can be established at the growth area where a ladder, spill kit, and so on, can be always accessible; only jar size and sequential number needs to be considered** |
| Reshelving (typically of returned loans) | Slower and more error prone: Same as initial shelving above | **Faster and less error prone: Find the void in the sequence left by removed jar** |
| Pulling or perusing specimens from a single species | **Faster: Once the species has been found, all the jars should be found nearby in a small area** | Slower: The database must be consulted to provide a list of catalog numbers, and those jars must be pulled from various locations throughout the collection |
| Pulling or perusing specimens from a single collecting event, project, or accession | Slower: The database must be consulted to find a list of species and catalog numbers; those jars must be pulled from various locations throughout the collection | **Faster: The database must be consulted to find a list of catalog numbers, but they are typically found together (if they were cataloged sequentially); once the area of the event or accession is found, all the jars should be found in a small area** |
| Pulling or perusing specimens from multiple collection events and multiple species | Slower: The database must be consulted to find a list of species and catalog numbers, but finding jars requires finding species, which can be time consuming | **Faster: The database must be consulted to find a list of catalog numbers, but finding jars in a sequenced array is faster** |
| Taking visual (quick) inventory | Slower and more error prone: Some of this can be achieved by simply looking for gaps among the jars; but this is harder for areas of the collection with many different species bunched close together, especially if various jar sizes are used | **Faster and less error prone: Simply look for gaps or loan tags that are easily observed among jars that are all the same height** |
| Taking detailed inventory (checking jars off of a list) | If the inventory is within a single taxon, the TAA is more efficient (see "Pulling specimens" scenarios, above) | If the inventory is within a collecting event, accession, or scattered throughout the collections the OCA is more efficient (see "Pulling specimens" scenarios above) |
| Evaluation of space remaining (for growth and planning) | Slower and more error prone: Each shelf must be viewed and a percentage of space estimated for each and summed | **Faster and less error prone: It is easy to see the number of empty aisles and shelves all on one end of the range** |

Table 1. Continued

| | Taxonomic alphabetical arrangement (TAA; with spaces for growth) | Object size and catalog number arrangement (OCA) |
|---|---|---|
| Reshelving after taxonomic changes and redeterminations | Slower and more error prone: The jar must be moved to a new location (see "initial shelving of incoming specimens"); if jar labels are not changed to indicate the new name, it becomes likely that eventually the jar will be misshelved | **Faster and less error prone, but probably not necessary: Since the system is not based on the taxonomic identification of a specimen, the jars retain their permanent positions; species names on the label do not necessarily have to be changed as long as the database is updated** |
| Reshelving misshelved jars | **Faster: If a jar is misshelved, jars must be shifted, but only within the species it was moved to and from** | Slower: If a jar is misshelved it is easy to rectify if caught before many subsequent jars have been shelved; the jars shelved after the misshelved jar must be shifted to accommodate the change; we recommend leaving small regularly placed spaces for rectifying this problem without having to move too many jars |
| Actions that would result in transferring specimens to larger jars (e.g., adding specimens to existing jars due to combining lots) | **Easily accommodated by increasing jar size and reshelving; may have to adjust jar positions, within the species, to accommodate larger jar** | Not easily accommodated since often many jars would have to be shifted; one way to deal with this is to catalog the additional specimens with a new number and shelve them on the last shelf |
| Actions that would result in transferring specimens to smaller jars (e.g., removing specimens from jars due to splitting lots, deaccessioning specimens) | **Easily accommodated by decreasing jar size and reshelving; may have to adjust jar positions, within the species, to reduce unused space around a smaller jar** | Not easily accommodated since often many jars would have to be shifted; one way to deal with this is to maintain the overly large jar in its permanent position on the shelf, despite its sparse contents |
| Dealing with taxonomic splits causing species name change (e.g., single species split into more, typically across multiple basins for fish) | Slower: After database update, new labels must be generated and placed in jars; jars must also be moved to new location based on their new name | **Faster: Database must be updated, but requirement to change labels is optional because their location does not depend on it; specimens will not be moved** |
| Specimen age-dependent maintenance routines (topping off alcohol, checking alcohol concentrations and pH, evaluating condition of specimens) | Slower: Jars of any particular age are distributed across the collection; however, it may be easier to visually inspect alcohol levels among variably sized jars in a TAA with the exception of small jars behind large jars | **Faster: Jars of any particular age should be together; we note that ease of visual inspection of alcohol levels will depend on the type of jar; for example, jars that taper inward toward the opening are easily assessed in the OCA, and especially so if pull-out drawers are used** |

Table 1. Continued

| | Taxonomic alphabetical arrangement (TAA; with spaces for growth) | Object size and catalog number arrangement (OCA) |
|---|---|---|
| Replacing defective or unsatisfactory curatorial materials (labels, jars, lids, seals, fluids, and so on); periodically when manufacturers produce new items and discontinue old items, collections discover defects requiring pulling and replacing; similarly new staff can make mistakes necessitating corrections | Slower: These jars are usually scattered through the collection and need to be pulled and then replaced from many disparate locations | **Faster: All of the jars shelved using a specific curatorial supply or that have been worked on by a particular worker should usually be together and easily pulled for correction and reshelving** |

As part of our Fishes of Texas Project, and for other reasons over the courses of our careers, we've traveled to many fish collections across the country to examine specimens. The ubiquity of the TAA system ensures that visitors familiar with natural history museums can work almost seamlessly in any collection. But, probably the most important benefit of the TAA is that it allows perusability within a taxon. For example, in our work we often need to see individuals of a particular size, sex, or reproductive state, either for fulfilling a loan request or locating reference material for our own research. Manually searching among the jars for individuals is a very effective way to find what is needed. This is not possible under the OCA, since jars of any particular species are widely distributed. However, as a consolation, we have found that it is often beneficial, especially for collection management purposes, to peruse the sequentially arranged shelves by collecting event, project, or accession. Because we typically catalog all of the lots from an event at once, they end up coalesced in the shelves. This is useful for specimen determination checking, or relabeling for errors determined to be universal across a project or event.

We find that our database can mitigate much of the loss in species perusability in the OCA. Largely thanks to the time saved by our workers no longer shuffling jars, it is now routine to count the individuals in each jar, to measure the largest and smallest, and to more consistently take digital images of specimens. Additionally, recording determiners' notes, which often include presence of parasites, deformities, sex, specimen condition, and so on, in our database allows us to better pinpoint the jars we need to pull without physically viewing the specimens. Obviously, improving the database in these ways also provides a more useful resource for researchers accessing our data online.

However, the greatest advantage of the OCA (apart from space efficiency) is probably the substantial time savings and accuracy for the tasks most often performed in our collection: initial shelving, pulling, and reshelving of jars (Table 1). One additional advantage we did not foresee is that the continuous expanse of empty shelf space at the end of the range would be useful for organizing specimens and could serve as a surge space to further improve efficiency. Although we have not implemented it yet, an OCA implemented with a simple shelf address system, labeled shelves, and database populated with permanent jar addresses could speed specimen finding. The addresses could be printed on the permanent jar labels to speed up reshelving as well.

### *Collection Growth over Time*

In growing TAA collections, steady reduction of growth space between species is inevitable and problematic. This eventually results in obligate shifting of species or groups of species—reducing space between some to make space for growth in others. A particularly burdensome event for managers of a crowded TAA is the addition of new species (e.g., what might be produced from a survey of a region outside the historic scope of the collection or establishment of a new invasive). It is highly unlikely that sufficient spaces were left when the collection was first established to accommodate such unforeseeable additions. In an OCA, all available space is contiguous and, once shelved, there is never a need to adjust. Growth capacity is obvious and easy to precisely quantify.

During our visits to other museums and in our own collection, we have noticed problems attributable to worker error, often due to attempts to compensate for this weakness of the TAA. All are problematic for collection managers and/or conflicting with fire codes. The most obvious relate to what workers do when there is no space remaining for new jars. We've seen misshelved jars on the floor (subject to being knocked over), filling between-jar spaces (causing ordered rows to merge), on unoccupied nearby shelves (rendering that lot essentially "lost"), or even stacking of jars as many as three high (making pulling of specimens difficult, and precarious as well). In our own collection, we have found jars that we think were deliberately misshelved by novice workers, far from where they were supposed to be, and therefore effectively lost.

TAAs are inherently space-inefficient, but, perhaps worse, the entirety of the space a TAA collection occupies will likely never be completely full. Even though space for growth exists, it inevitably will be in the wrong places, and managers will eventually have to make the decision that it is not worth the effort to shuffle so many jars. OCAs can be filled to capacity without decreasing efficiency over time as the space fills (Fig. 6).

Once a space is full, acquiring additional space is an obvious solution, albeit not always feasible. But moving a TAA into new space is far from easy. Depending on the size of the new space, the easiest solution might be to start a duplicate system there, essentially maintaining two collections and leaving most species split across the two spaces; or the entire collection could be laboriously spread across both spaces. With an OCA system, once a space fills (all shelves containing their maximum number of jars), new growth can simply continue into the new space, leaving jars in the first space untouched. The OCA is modular in that as new space is acquired, a collection can simply grow into it, and this can happen indefinitely. It also eliminates human effort to move collections, allows for flexibility in collection housing (multiple small spaces can be added), and reduces the chances that specimens are lost or damaged during moves.

### *Shifting Taxonomies and Name Changes*

There is no single taxonomy that all TAA collections use, and no matter what taxonomy is implemented, it will change as science advances. Linnaeus, the first user of the TAA, thought of species names as being fixed (Reid 2009) and therefore, such a name-based shelving system made sense. However, now we know that those species names are far from static, are often in dispute, and are thus problematic as a basis for organizing a collection. Differences in taxonomies among collections can make it somewhat difficult for individ-

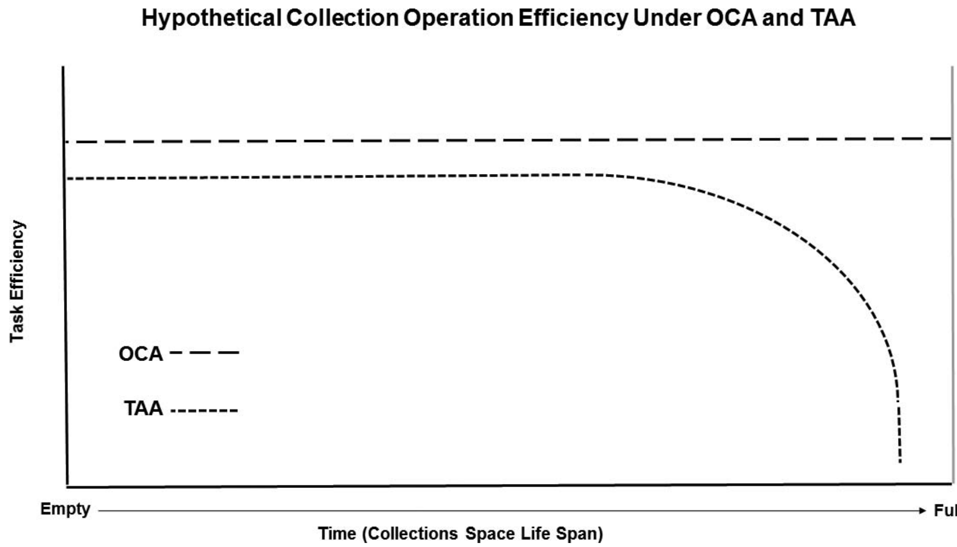


Figure 6. Hypothetical comparison of task efficiency, for common tasks, under the TAA and OCA projected through time until the collection's space is fully used. The OCA allows for better efficiency until the space is completely full. The TAA, although relatively efficient at first, eventually becomes unworkable as the space is filled—not all space will be used due to gaps caused by coshelving of variably sized jars and because spaces left for growth between species become impossible to maintain.

ual researchers to work seamlessly across TAA collections, but for managers of collections, taxonomies are more problematic.

Taxonomic changes are frequent, and the naming of new species continues to increase (Costello et al. 2012), largely due to improvements in genetic analyses that can detect and split morphologically similar species. Adjusting TAA collections for taxonomic splits is often time consuming for collections staff because they must pull specimens of the new species from one section, relabel them, consolidate them in another location, and update their database. This can be particularly time consuming for a species represented by many jars. It can be prohibitive for splits at higher taxonomic levels.

For any of the cases causing names to change (e.g., taxonomic revision, specimen redetermination), under the TAA, protocol dictates that labels be updated to reflect the new name, or the jar will potentially be misshelved. However, the OCA is based on a static catalog number, so the jar's position never changes even if the name changes. Changing species names on labels also becomes less of a requirement and more of a preference—databases can account for taxonomic synonymies. In fact, it might be considered acceptable by some collection managers to label jars with no more than a unique identifier, such as a catalog number or barcode, because those are the only pieces of data that are inarguably static and required for shelving.

## *Specimen Monitoring*

Proper collection management entails periodic monitoring of containers and specimens to ensure housing conditions are maintained and to prevent specimen deterioration. Arrangements of fluid-preserved collections ideally should allow jars, specimens, and fluid levels to be visually evaluated with minimal jar movement. A space-limited TAA often provides visibility, depending on its implementation, but it can often obscure smaller jars behind larger jars, which must be moved to examine the collection. The OCA crowds jars of the same height, preventing lateral visibility for all but the first row. But, when implemented with jars having sufficiently wide shoulders, fluid can be observed from the top (if pull-out shelving is used) or at an angle (if fixed shelving is used).

In our OCA, on fixed shelves, with relatively narrow-shouldered jars initially filled to the top, we can evaluate fluid levels for all jars on even our most densely packed shelves. However, we need to use a flashlight to see them well, and a full view of specimens beyond the first row of jars is not possible without lifting each jar. We sometimes have difficulty determining fluid level if the fluid/air interface is concealed by the lid or below the edge of the shoulder, but if we move each jar slightly the movement of the fluid reveals the level. Consequently we have adjusted our protocol to fill jars to the bottom of the jar threads to allow us to jostle the jar to visualize fluid levels. We tested fluid evaluation rates on three shelves of our smallest jars with the narrowest shoulders and determined that we were able to evaluate them at a rate of one fully packed shelf (112 jars) in 78 seconds. The system could be improved by using jars with wider shoulders, and we are currently experimenting with storing jars lid-side down, which would allow far greater visibility.

### *Specimen Condition and Longevity*

One of the central tenants of the preventative conservation approach to maintaining collections (Rose et al. 1995, Simmons 2015b) is that the environment (e.g., temperature, humidity, light) be held stable, and that objects be moved and handled as little as possible to reduce mishandling, exposure to light, and label dissociation. The OCA, which tightly packs specimens, reduces light penetration to specimens in the interior of the storage space. We suspect this tight packing would also stabilize temperature because larger volumes of fluid are more resistant to fluctuation due to a lower surface area to volume ratio. Depending on air flow, this effect might be stronger for specimens housed deeper in the shelving area, especially if shelves can be adjusted vertically to increase jar density, and greater still if horizontal compactors can be installed. Because lids can often loosen due to fluctuating temperatures, seals in an OCA system should be more stable and alcohol vapor retention should be improved.

The larger benefit for specimen conservation relates to the fact that, once shelved, jars do not require as much handling in an OCA. The constant shuffling of jars to make space for growth in a nearly full TAA does not occur in an OCA. Because the OCA is modular (as previously described), existing jars can stay in place when more space for growth becomes available. Because most of the activity, depending on the collection, occurs where incoming specimens are being added, the human traffic in an OCA occurs primarily in a relatively small area, whereas in a TAA it is spread throughout the collection, increasing the chances of bumping shelves and breaking jars. In an OCA, because smaller jars are not hidden behind larger jars and catalog numbers are in sequence, it is less likely that jars will be accidentally bumped or forced off shelves when users search for specimens. But, when multiple jars are dropped simultaneously near each other, which often results in a jumble of labels and specimens (e.g., an earthquake), their contents should be easier to sort back into lots since they will much more likely contain different species.

OCAs facilitate specimen care-related tasks better than do TAAs. Any operation in the collection that relates to the date of cataloging is likely easier in an OCA since jars are arranged in catalog order. This consolidates the jars cataloged at a particular time interval. Staff can check fluid levels or specimen condition in jars of a selected age efficiently because the jars should be located together. Similarly, defective materials (e.g., lids, labels, inks) could be corrected easily because affected jars would not be scattered around the entire collection, as would be the case in a TAA. Likewise, if a collection worker was determined to be unreliable, it would be easier to find the jars worked on by that individual to check their work.

### *Drawbacks of the OCA and Workarounds*

In addition to losing taxonomic perusability, the largest drawback of OCAs is that, when shelving mistakes are made (either a jar is incorrectly inserted or left out), it can be time consuming to fix if many jars have been subsequently shelved. The system should be employed with this in mind, and a double-checking system should be implemented to detect these sorts of problems before many subsequent jars are shelved. Double checking in OCAs is relatively easy, since potential problems would occur in a small area. Managers of TOAs typically do not double-check shelving accuracy because the process would be too time consuming. To account for this type of error, we started leaving "contingency" spaces—an empty jar row on every tenth shelf, which ensures we will never have to move more than 10 shelves worth of jars. This may be more than is required given that we have not had to use any contingency spaces in the six years of testing the OCA. If, for whatever unforeseen reason, the periodic empty rows were not sufficient, we dedicated a small area at the end of the range for jars that fail to be incorporated in their proper place in the range. A cardboard tab would then be placed where the jar is supposed to go, indicating its position on the overflow shelf. This is not ideal, but it is functional, and we hope not to have to employ this solution.

One of the biggest drawbacks of converting to the OCA is not a problem with the arrangement itself but rather relates to the difficulty of converting from a TAA. To convert, which we have yet to do, since our OCA only includes newly cataloged specimens, requires pulling all of the jars from the TAA, sorting them into sequential order, and moving them to new places starting at one end of the new range. If the OCA is to occupy the same space as the TAA, this process becomes more complicated, and surge space will likely be critical. Workers must reserve a spot in the OCA for any jars not found (usually loans or lost specimens) by leaving a space empty or by using upside down jars as placeholders. It is important that the size of the missing jar be known so its position can be determined. If mistakes are made in this regard the workarounds already described could be employed. Large collections, suffering greater physical inertia, are understandably hesitant to make changes that affect physical housing, labeling, and especially shelving arrangements of their specimens. The logistics of converting a large collection would clearly be daunting. This probably explains, at least in part, why collections have been arranged the same way, using variations of the TAA, since the practice of modern collecting began. It may be that smaller collections, with their comparatively fewer jars, can convert more easily and will test the arrangement.

### *Usability of the OCA across Disciplines*

Our own experience is limited primarily to ichthyology collections holding fluid-preserved specimens in jars and smaller, but similar, subcollections (osteology, cleared and stained specimens, otoliths, and larval fishes). Our situation may be uniquely suited for the OCA, but we expect that this system can be widely used by many other collections, including those holding objects in containers other than jars (e.g., boxes, folders, bags), those using no container at all, or those with combinations of abiotic and biotic objects. The arrangement works best when all of the objects to be included all require the same environmental conditions (because they will be cohoused) and similar care. It is conceivable that collections using this system could cohouse specimens from more than one discipline, greatly increasing efficiency. For example, fluid-preserved specimens of fish, herps, and aquatic invertebrates could be shelved together. The system works best when containers hold one catalog number. Multi-lot containers are not workable in this system, unless specimens are sequential within each multi-lot container and the multi-lot containers match the sizes of the other containers in the collection. Multi-containers (jars or tanks) are probably best stored separately. If the OCA is applied to a collection with many size categories, or sizes similar enough as to not be easily categorizable, the collection may be hard to use. We recommend having no more than four distinct size categories. Lastly, collections that use decimal or alphanumeric catalog numbers need to consider how their catalog number conventions might affect their ability to retrieve jars, but this does not seem to us to prevent usage of the OCA.

Every collection has a mission and audience, and the OCA system may not be appropriate for all collections, even if they might be able to convert. For example, collections that routinely allow researchers direct access to shelved specimens may have good reason to maintain the familiar TAA system. The OCA does not facilitate the use of the collection by taxonomically focused scientists in the same way as the TAA (although it does not preclude them access). Also, collections with few specimens and/or few species, or those with a plan to curtail growth, would have little need to change arrangements.

## Conclusion

Generally, collections are underfunded (Suarez and Tsutsui 2004, Paknia et al. 2015, Yong 2016), while at the same time the work load for managers of collections is increasing—online data provision, data digitization, specimen imaging, maintaining genetic resource collections, linking specimens to their derivatives (Lendemer et al. 2020), and so on. As spaces become filled with specimens, and the desire to continue to build those collections continues, the strain on collections staff and resources is increasing. It is critical that collection managers think carefully about their collection's mission, the efficiency of their operations, and the use of space and staff time.

Despite the problems we've identified in the OCA, we believe it to be a better system, from a managerial perspective, than the TAA, which we have now worked with for a combined 54 years. We've recognized a growing need among collections for space-efficient storage of specimens and have seen first-hand the problems with the TAA while visiting many of the collections in North America. John E. Simmons has repeatedly described some of the same problems (Simmons 2013, 2015a, 2015b). He states that "Storage arrays should be designed to provide the best environment and most efficient use of space, rather than being based primarily on classifications or taxonomies" (Simmons 2015b) and that (quoting Petrie 1900) "the shifting and rearranging of objects must be avoided as much as possible; and building must be capable of interminable expansion at any point, so as to allow of incorporating large collections without moving everything else to agree" (Simmons 2013). The OCA accomplishes these things. The TAA was developed when collections were drastically smaller, before modern digital databases, by scientists to facilitate scientific research at the time. As collections grew into vast archives, they needed management by dedicated staff who continued the TAA, but the arrangement, in our view, can now be replaced in many collections.

Because all of the services provided by collections are directly affected by how collections are managed, it is worth considering the alternative, that collections should not be managed for scientists to use directly on site, which the TAA facilitates, but for the efficiency of management by professional collection managers, which the OCA facilitates. We are confident that the OCA will protect specimens, save our workforce significant time that can be redirected in productive ways, and make our limited space last longer.

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