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Contributed Paper

Dynamics in the global protected-area estate since 2004

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Abstract: *Nations of the world have committed to a number of goals and targets to address global environmental challenges. Protected areas have for centuries been a key strategy in conservation and play a major role in addressing current challenges. The most important tool used to track progress on protected-area commitments is the World Database on Protected Areas (WDPA). Periodic assessments of the world's protected-area estate show steady growth over the last 2 decades. However, the current method, which uses the latest version of the WDPA, does not show the true dynamic nature of protected areas over time and does not provide information on sites removed from the WDPA. In reality, this method can only show growth or remain stable. We used GIS tools in an approach to assess protected-area change over time based on 12 temporally distinct versions of the WDPA that quantify area added and removed from the WDPA annually from 2004 to 2016. Both the narrative of continual growth of protected area and the counter-narrative of protected area removal were overly simplistic. The former because growth was almost entirely in the marine realm and the latter because some areas removed were reprotected in later years. On average 2.5 million km^2 was added to the WDPA annually and 1.1 million km^2 was removed. Reasons for the inclusion and removal of protected areas in the WDPA database were in part due to data-quality issues but also to on-the-ground changes. To meet the 17% protected-area component of Aichi Biodiversity Target 11 by 2020, which stood at 14.7% in 2016, either the rate of protected-area removal must decrease or the rate of protected-area designation and addition to the WDPA must increase.*

Keywords: Aichi target 11, coverage, protected area, protected area downgrading downsizing degazettement, World Database on Protected Areas

Dinámica de los Bienes de las Áreas Protegidas desde 2004

Resumen: *Países alrededor del mundo se han comprometido con un número de metas y objetivos para tratar los retos ambientales mundiales. Las áreas protegidas han funcionado durante siglos como una estrategia clave en la conservación y juegan un papel importante en cómo se manejan los retos actuales. La herramienta más importante que se usa para rastrear el progreso de los compromisos con las áreas protegidas es la Base de Datos Mundial de las Áreas Protegidas (WDPA, en inglés). Las evaluaciones periódicas de los bienes de las áreas protegidas muestran un crecimiento constante durante las últimas dos décadas. Sin embargo, el método actual, que usa la versión más reciente de la WDPA, no muestra la verdadera naturaleza dinámica de las áreas protegidas a lo largo del tiempo y no proporciona información sobre sitios que han sido removidos de la WDPA. En realidad este método sólo puede mostrar crecimiento o permanecer estable. Usamos herramientas de SIG en una estrategia para evaluar el cambio de las áreas protegidas a lo largo del tiempo con base en doce versiones temporalmente distintas de la WDPA que cuantifican las áreas añadidas o removidas de la WDPA*

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anualmente desde 2004 hasta 2016. Tanto la narrativa del crecimiento continuo de un área protegida como la contra-narrativa de la eliminación de un área protegida fueron exageradamente simplistas. La primera se debe a que el crecimiento ocurrió casi en su mayoría en el dominio marino y la segunda a que algunas áreas eliminadas fueron reprotegidas años después. En promedio se añadieron 2.5 millones de km^2 a la WDPA anualmente y 1.1 millones de km^2 fueron removidos. Las razones para la inclusión y la eliminación de las áreas protegidas de la base de datos de la WDPA se debieron en parte a temas de calidad de datos pero también a cambios hechos sobre la marcha. Para lograr el 17% del componente de áreas protegidas del Objetivo 11 de Biodiversidad de Aichi para el 2020, el cual se encontraba al 14.7% en 2016, se debe disminuir la tasa de eliminación de áreas protegidas o se debe incrementar la tasa de designación y suma de áreas protegidas a la WDPA.

Palabras clave: área protegida, Base de Datos Mundial de las Áreas Protegidas, cobertura, degradación reducción y pérdida de protección legal de las áreas protegidas, objetico 11 de Aichi

摘要: *世界各国都在致力于实现一系列目标以应对全球环境变化的挑战。几个世纪以来, 保护区一直是实施保护的重要策略, 在应对目前的挑战中也起到重要作用。要追踪对保护区建设实施的进展, 最重要的工具就是世界保护区数据库 (World Database on Protected Areas, WDPA) 。对全球保护区的周期性评估显示, 过去二十年来受保护的区域在稳定增加。然而,目前使用最新版本 WDPA 数据库的方法并不能体现保护区随时间变化的真实动态, 也不能提供那些从 WDPA 中去除的位点的信息。事实上, 这个方法只能显示增长或保持稳定的动态。我们用 GIS 工具, 根据 12 个不同时期的 WDPA 版本评估了保护区随时间的变化, 这一方法定量了 2004 年到 2016 年 WDPA 每年新增和去除的地区。保护区的持续增加和保护区的去除的描述都过于简单化。前者是因为增加的地区几乎都是海洋, 后者则是因为一些被去除的地区随后几年又重新得到了保护。 WDPA 中保护区平均每年增加 250 万平方公里, 去除 110 万平方公里。 WDPA 数据库中保护区新增和去除的原因有的是数据质量问题, 有的则是发生了真实的变化。为了在 2020 年达到爱知生物多样性目标 11 中保护区覆盖 17% 的目标 (2016 年为 14.7%), 必须降低保护区被去除的速率, 或增加划定保护区并加入 WDPA 数据库的速率。***【翻译:胡怡思;审校:聂永刚】***

关键词: 保护区, 世界保护区数据库 (World Database on Protected Areas), 覆盖, 保护区降级、缩小、撤除, 爱知目标11

Introduction

In the 21st century, when humanity's footprint has touched 75% of the terrestrial world and much of the ocean (Halpern et al. 2015; Venter et al. 2016), protected areas are almost synonymous with conservation. Protected areas are defined as "... clearly defined areas that are recognized, dedicated and managed to achieve long-term conservation of nature ..." (Dudley 2008), and are reported to cover 14.7% of Earth's land and inland waters and 4.1% of Earth's oceans (UNEP-WCMC and IUCN 2016), making protected areas one of the major land and sea uses. As such, they are recognized as a key strategy to address some of the global environmental challenges the world is facing. This is reflected in a number of global biodiversity agreements that use protected-areas data to assess progress toward a number of targets and goals. For example, protected areas are at the core of Aichi Biodiversity Target 11, 1 of the 20 targets agreed on by 196 countries through the Strategic Plan for Biodiversity (Convention on Biological Diversity 2010), which aims to expand protection to cover 17% of land and inland water areas and 10% of the oceans by 2020. It also aims to meet several other equally important qualitative attributes, such as effective and equitable management (Convention on Biological Diversity 2010). Protected-areas data are also used to track progress toward at least 3 indicators of the United Nations Sustainable Development Goals (SDGs) (UNEP-WCMC and IUCN 2016; United Nations Statistics Division 2016). For example, SDG Goal 14 (conserve and sustainably use the oceans, seas, and marine resources for sustainable development) includes Target 14.5, which aims to conserve at least 10% of coastal and marine areas consistent with national and international law and is underpinned by the WDPA. Protected areas are also relevant to regional and global biodiversity assessments carried out for The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES 2016). Indicators used to track progress toward these commitments benefit from analyses of temporal trends of protected areas, which illustrate how the protected-area estate has evolved over time.

Focusing on Aichi Biodiversity Target 11, assessing the growth of protected-area coverage over time is fundamental, but it is only a single element of the full target, which also incorporates factors such as effectiveness, connectivity, and equity and therefore at best provides only a generalization of overall progress (Juffe-Bignoli et al. 2014). Moreover, some argue that the area-specific aspects of the target merely represent political decisions that do not resemble any biologically meaningful number (Larsen et al. 2014; Locke 2014). This position echoes the scientific literature that shows continuing biodiversity loss globally, despite strong progress in protected-area coverage (e.g., Butchart et al. 2010; Barnosky et al. 2011; Tittensor et al. 2014; Newbold et al. 2016), and evidence for the ability of protected areas to effectively conserve species (Joppa & Pfaff 2011; Laurance 2012; Barnes et al. 2016).

Understanding how protected-area coverage has changed over time and understanding the nature of these changes will remain a fundamental part of trend analyses of protected areas and key to assessing progress toward targets in the future. All global-scale protected-area coverage analyses are based on the World Database on Protected Areas (WDPA). The WDPA is the most comprehensive database on terrestrial and marine protected areas and is a joint project between UN Environment (UNEP) and International Union for Conservation of Nature (IUCN), managed by UN Environment-World Conservation Monitoring Centre (UNEP-WCMC 2016). Following a 1959 UN mandate (United Nations Economic and Social Council Resolution 713 [XXVII]) that is supported by 14 decisions by the Conference of Parties of the Convention on Biological Diversity, data on protected areas are collected from over 500 mainly governmental, but also nongovernmental, sources and updated on a monthly basis at www.protectedplanet.net. Thus, the WDPA provides a picture of the current protected-areas global estate. It is therefore the primary resource for calculating the current coverage of protected areas globally; however, its use in calculating coverage over time has underappreciated limitations.

Current approaches for estimating protected-area coverage over time are based on the year in which areas were gazetted (hereafter the existing approach), which is represented in the WDPA by the field of status year. Using this field and eliminating overlaps to avoid double counting, total protected area is obtained by cumulatively adding the area of all designated protected areas for each year to the present date; as such, the result does not provide information on any change or reduction in protected area from year to year. Those who have used this approach similarly found a continual increase in protected area from the start of the time series (Bertzky et al. 2012; Butchart et al. 2012, 2015; Juffe-Bignoli et al. 2014; UNEP-WCMC and IUCN 2016). This approach has 2 key limitations. First, because it is a cumulative analysis, it cannot show a reduction in area. Second, because the WDPA is a snapshot of all designated protected areas at the time of its release, it does not include protected areas that have been degazetted. Reductions in the protected-area estate occur (Mascia et al. 2014), as shown for example in the tracker database PADDD (Protected Area Downgrading, Downsizing, and Degazettement) (http://www.padddtracker.org) (World Wildlife Fund [WWF] 2017). This database highlights a counter narrative to the narrative of continual protected-area growth, one in which the protected-area estate is being weakened and made smaller.

Degazettement or downsizing events need not be damaging to conservation efforts (Fuller et al. 2010), and reviewing protected areas to assess their efficacy is a healthy process (Hochkirch et al. 2013). However, the potential implications of wide scale degazettement or downsizing occurring without it being recorded in existing time-series analyses could significantly undermine conservation efforts. This counter narrative is seen in reported protected-area statistics: a 15.4% to 14.7% reduction in terrestrial protected area from 2014 to 2016. This change shows the protected-area community needs more sophisticated knowledge of protected-area dynamics and a better understanding of where sites are being removed and added to the WDPA over time. Moreover, the separated narratives of protected-area expansion and reduction in conservation science literature hampers understanding of the dynamic nature of the protected-area estate, which includes the creation of new sites via gazettement, removal of sites via degazettement, expansion of existing sites, and reduction in area of existing sites.

We sought to highlight the limitations of the existing approach to calculating protected-area coverage change over time; devise a new way to calculate protected-area coverage change over time (hereafter temporal WDPA approach); calculate gains and losses in the WDPA at the global and national scale with this new method; and to consider our results relative to observed increases in Aichi Biodiversity Target 11 coverage and the PADDD literature showing coverage decline in order to balance the narrative and illuminate the nuances of protected-area expansion and reduction. We hope such a baseline methodological study furthers more refined attempts to better encapsulate the dynamic nature of the world's protected area estate.

Methods

Assessing the Existing Approach

To assess the widely used existing approach for tracking protected area cover change over time, we used an established method (Juffe-Bignoli et al. 2014; UNEP-WCMC and IUCN 2016) to calculate time series for 2 different versions of the WDPA: the 2014 and 2016 Protected Planet reports. This was done to demonstrate that even the existing method can produce quite different time-series results depending on the version of the WDPA (Fig. 1). The method was the same for both time series (see Supporting Information). Protected areas in each version of the WDPA were split according to the year of their designation in their current form, as recorded in the status year field. The overlap between the protected areas was removed in GIS and then the sum of each year's area was added sequentially until the year of the WDPA

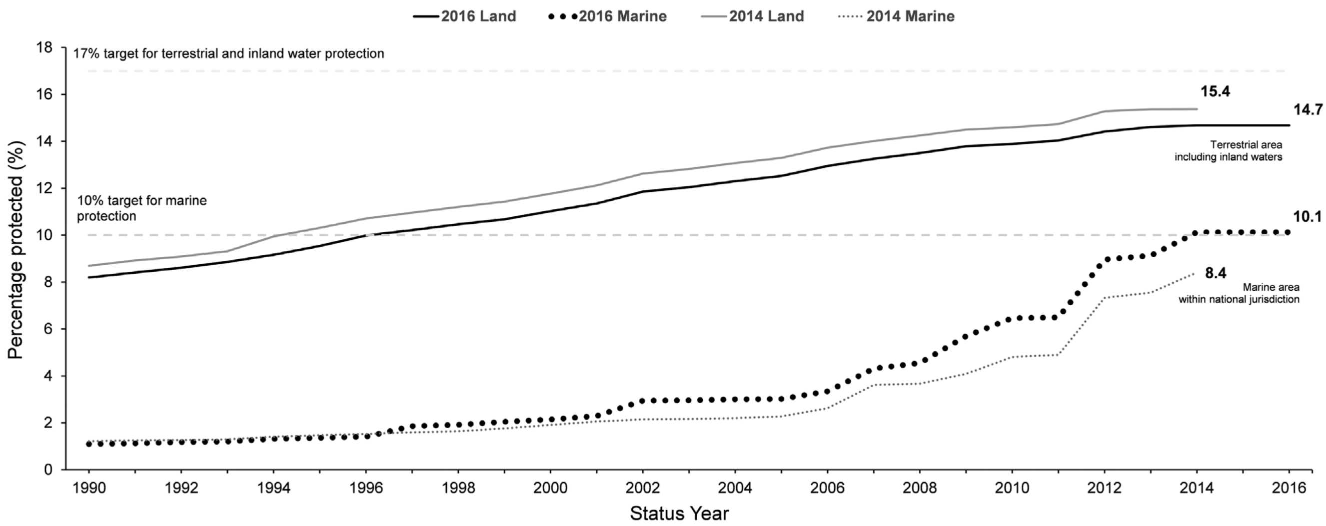

Figure 1. Protected-area growth calculated from the 2014 and 2016 versions of the World Database on Protected Areas (WDPA) with the established method (status year, field used for analysis, and year in which areas were gazetted).

version used in the analysis. For those protected areas for which status year is unknown, we added them to the first chosen year of the analysis, in this case 1990. This method resulted in the total area of the global protected area estate per year, as reported via the designation date of the current assemblage of protected areas reported to the WDPA.

Temporal WDPA Approach

To develop a new method to calculate protected-area change over time that could show in more detail how the WDPA changes between years, we created a novel database, the temporal WDPA. This database consisted of 17 annual versions of the WDPA from 1998 to 2016; the years 1999 and 2001 remain missing. Each annual version was created by combining multiple historic WDPA subsets with the current WDPA schema. The versions were enormously diverse in regard to format and spatial and tabular data quality. Combining these databases required standardizing field metrics, field types (numeric or text), and essential accepted values and checking for duplicate protected areas between intra-annual data sets. We used the years 2004 to 2016 to give a snapshot of changes between the 2003 World Parks Congress and the 2016 World Conservation Congress—2 international events where the WDPA featured as a key global resource.

Each annual version was composed of a point and a polygon feature class. Points were buffered in accordance to their reported area and merged to the polygons to create 1 definitive feature class per year. Buffering points has some important limitations (Visconti et al. 2013), but we used this technique because annual versions of the WDPA before 2007 consist predominantly of points. Each annual version was flattened with GIS tools to remove overlaps between protected areas. It is common practice to remove certain sites from the WDPA; however, we used the entirety of the WDPA in each version because the tabular information required to identify sites for removal is not yet in every version of the WDPA. There are, therefore, sites in this analysis that are only proposed or have an unknown status. To compare protected area between the existing and temporal WDPA approach, we calculated a third time series with the existing approach that did not omit the specific sites of the previous 2 time series (Fig. 2 & Supporting Information). In essence, it is the entire WDPA per year through the lens of a single WDPA version, whereas the temporal WDPA is the entire WDPA through the lens of historic WDPA versions.

Calculating Area Flux

To provide a sensitivity analysis of current understanding of protected-area change over time, we examined how the WDPA loses area (negative footprint) and gains area (positive footprint) between versions of the WDPA.

To quantify the negative footprint, each nation in year x (e.g., 2009) was iteratively erased from the entire annual version in year $x+1$ (e.g., 2010), resulting in the unique area per nation removed from the WDPA in that time. Conversely, to calculate the positive footprint, we erased year $x+1$ from year x to yield the unique area added to the WDPA in that time interval. For each time interval, all countries were merged together to show the overall global area for that footprint. The global positive and negative footprints for each time interval were then overlaid on a base map of the world's coastlines to further delineate the extent to which the positive and negative

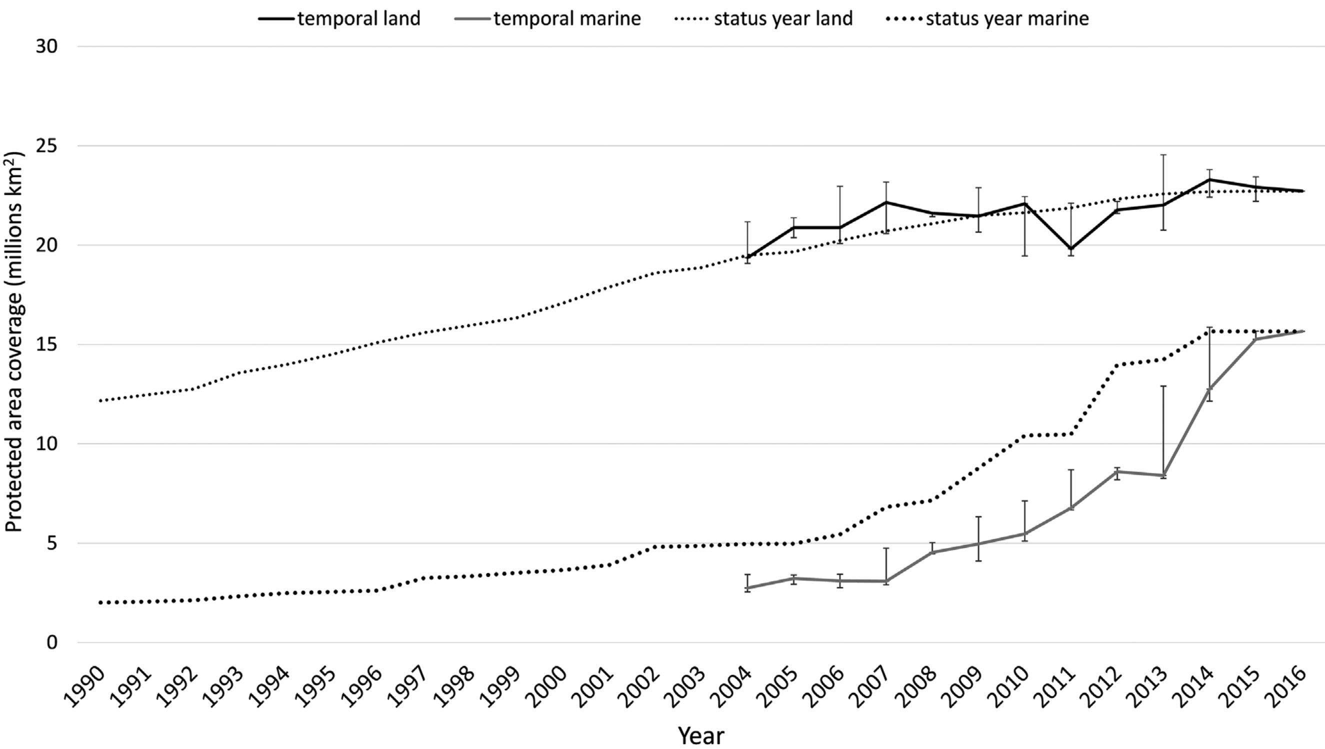

Figure 2. Total global protected-area estate (terrestrial + marine) based on the status-year (the year in which areas were gazetted) method, which misses changes in area coverage that occur every year (bars, positive and negative footprints between each time interval).

footprints were occurring over terrestrial or marine realms. The sum of the positive and negative footprints in each time interval was equal to the net change between the 2 versions of the WDPA because each represented the total area gained and lost (error margin of 0.05%).

The negative footprint was of particular interest and was used in 2 additional analyses. First, each negative footprint in each time interval was erased from the 2016 version of the WDPA to show how much of that time interval's negative footprint remained absent from the WDPA and what proportion was reprotected at some point in the last decade. Second, each negative footprint was repeated using solely polygons as input, thereby demonstrating the proportion of each negative footprint consisting of known and detailed protected-area boundaries. The negative footprints were also compared with the sites recorded in PADDD tracker version 1.1 (World Wildlife Fund & Conservation International 2016). We compared the spatial location of PADDD points and protected-area boundaries in a case study of Uganda to show how the temporal WDPA can provide additional information on how the protected-area network has evolved.

To calculate the extent to which the WDPA changed at national and global scales over the last decade as a single time interval, positive and negative footprints were created using 2006 as year x and 2016 as year $x+1$. We used a decadal time scale because nations are not updated every year (on average 60 nations are reviewed annually) (Thomas et al. 2014; UNEP-WCMC 2016); therefore, we assumed that over the space of a decade a nation would be updated at least once.

Results

Assessing the Existing Approach

Based on the existing approach, the coverage of protected areas globally in 2016 was estimated to be 14.7% of terrestrial and inland waters and 10.1% of marine areas within national jurisdiction (0–200 nautical miles). The same method applied to the 2 previous years yielded15.4% and 8.4% coverage, respectively (Fig. 1). Despite a known reduction in global terrestrial coverage relative to 2014, the trend line based on the existing approach still showed continual growth since 1990 because this approach could not show declines. The growth to 2016 in the reported marine area since 2014 did not occur after 2014, when it plateaued; rather, it occurred from the late 1990s and thus reflects a reporting lag time. The terrestrial time series differed on average by 0.9 million km^2/year (range 0.5 million–1.1 million km^2), whereas the marine time series differed on average by 1.5 million km^2/year (range 0.08–4.2 million km^2).

The Temporal WDPA Approach

In total, the temporal WDPA grew from 120,883 protected areas covering 22.1 million km^2 in 2004 to 229,593 protected areas covering 38.4 million km^2 in June 2016. In comparison with the existing approach with the whole WDPA, the terrestrial time series differed on average by 0.1 million km^2 /year (range 0.03–2.1 million km^2). The marine time series differed on average by 3.6 million km^2/ year (range 1.7–5.8 million km^2).

Reporting area Flux

The positive footprint within the temporal WDPA each year was on average 2.5 million km^2 (SD 1.9), the vast majority of which was due to the addition of new protected areas to the database. There was also a negative footprint each year, which predominantly stemmed from the removal of protected areas from the WDPA, which on average accounted for the loss of 1.1 million km^2 /year (SD 774,000) (Fig. 2).

After 2004 there was considerable variance in the positive footprint between years; the smallest change was 7 times smaller than the largest change. Over the same period there was considerable variance in the negative footprint, although the smallest negative global footprint (2008–2009) still represented almost 250,000 km^2.

After 2004 there were 2 years when the positive footprint did not outweigh the negative footprint (Fig. 2). For 1 of these years (2010–2011) data quality was the underlying problem. The other instance (2005–2006) was due to a very small positive footprint.

On average the terrestrial realm accounted for 47.6% of the added area per time interval (range 14–86%), whereas it accounted for 71% of the removed area per time interval (range 31–99%). The majority of positive footprints arising in the marine realm stemmed from the inclusion of very large MPAs from 2013 onward (Fig. 2).

On average 79% (range 42–98%) of each year's negative footprint since 2004 was still absent from the WDPA in 2016. The high level of reprotection from 2010 to 2011 (Fig. 3) was due to data-quality problems. Counter to expectations, older negative footprints did not have a higher rate of reprotection. Half of the negative footprints consisted of area derived from buffered points (mean 52%, range 1–92%); however, negative footprints also demarcated proven PADDD events (Supporting Information).

From 2006 to 2016, most (69%) of the added area occurred in the marine realm. Much of the positive footprints demonstrated annually in Fig. 2 were attributed to only a handful of countries and territories in Asia and the Pacific, which accounts for 45% of the total reported global growth over the last decade and 57% of the reported marine growth. Many of the large contributors to the WDPA since 2006 are geographically large nations, but some of the largest contributors are small island states that owe the majority of their positive footprint to marine protected areas, some of which cover the entirety of the nation's territorial waters (0–200 nautical miles). For example, New Caledonia gazetted 1 protected area, the Natural Park of the Coral Sea, which is 1.2 million km^2.

By comparison, the negative footprint over the last decade is more diffuse. Although 223 countries and territories lost some of their reported protected-area estate from 2006 to 2016, this has not occurred predominantly in any single region. Similarly, the magnitude of the negative footprint at the national scale is significantly less than the positive footprint.

Discussion

Comparison of Approaches

Both time series showed that the amount of protected area globally is increasing but that this growth is effectively entirely within the marine realm; the terrestrial realm continues to plateau. The temporal approach did not therefore bring into question overall understanding of progress toward the coverage components of Aichi Target 11; rather, it provides a framework with which to better understand how the current global network evolved.

The average annual difference between the existing approach and the temporal approach was 0.1 and 3.6 million km^2 for the terrestrial and marine realms respectively. However, comparing 2 different time series with the existing approach resulted in an average annual difference of 0.9 and 1.5 million km^2, respectively, which means a clear or fixed understanding of historic protected-area coverage is lacking.

Neither approach is the correct approach. The existing approach underrepresents historic coverage because it omits degazetted protected areas, whereas the temporal WDPA underrepresents historic coverage because it uses versions that do not yet contain all protected areas gazetted to that date. Which bias is larger is unknown. Both methods showed variations in the order of millions of square kilometers. Both methods have strengths and weaknesses (Table 1), and in a sense, excel in 2 separate ways. The existing method is still the best at demonstrating a wide-ranging time series based on the most up-to-date data, but it is constrained in its ability to demonstrate anything but rate of net growth of still existing protected areas and hence masks the dynamic nature of change in protected-area coverage. Comparatively, the temporal WDPA has the capacity to quantify the additions, subtractions, and modifications over time, although at the cost of depending on potentially incomplete previous versions.

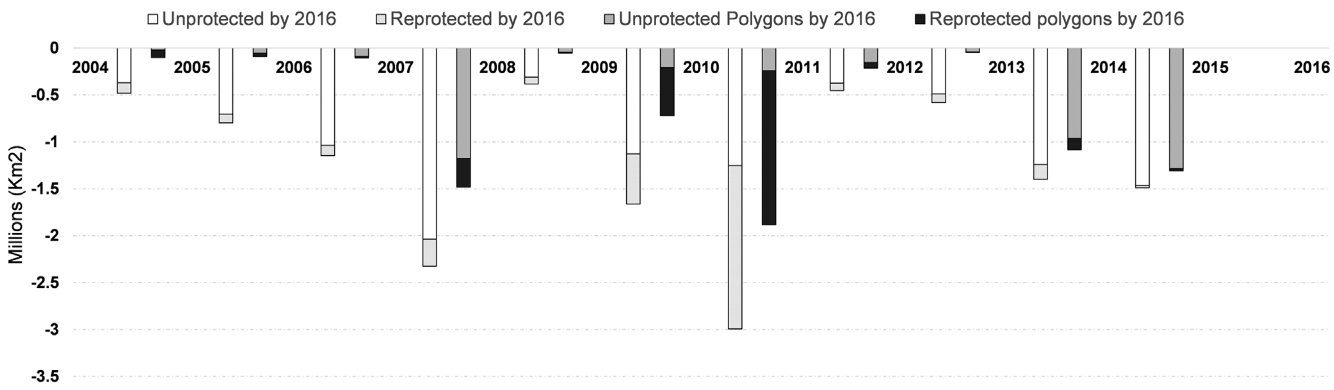

Figure 3. The negative footprints (i.e., loss of protected area) in every time interval since 2004 based on an approach that includes buffered points and an approach that is based on only polygons.

Table 1. Advantages and disadvantages of the existing approach and a temporal approach to creating a protected-area coverage time series.

Analysis method	*Advantages*	*Disadvantages*
Existing approach	can be used from the earliest year of designation (~1859) onwards uses best available (current) data, which has a lower proportion of protected areas with unknown boundaries quantifies additions at time of creation, not time of inclusion to the WDPA	can only show a time series depicting stability or growth; decline not captured can create markedly different historic coverage statistics depending on which version of the WDPA is used time series based on a single field, status year, which only reflects the designation date of the current cohort of protected areas in their current form not those that have been degazetted in the past computationally intensive because each year has to be recalculated for each analysis
Temporal WDPA	can track how protected areas change spatially (e.g., their size or boundary) can track how protected areas change contextually, e.g., their type of designation or management type historic coverage statistics are always the same because a year's footprint is fixed in a specific WDPA version increasingly robust database as new versions of the WDPA are added computationally quicker, only the current year's coverage needs to be calculated because coverage for previous years is already calculated	earliest data starts in 1998, though accurate data starts in 2004 older versions of the WDPA lack established sites due to reporting time lag older versions of the WDPA are increasingly data poor (e.g., proportion of points to polygons, empty or nonexistent fields due to limited sampling effort and lack of data standards) positive and negative footprints associated with the WDPA versions rather than the dates in which they occurred on the ground

Causes and Implications of Area Flux

Results of both approaches showed that over the last decade the majority of the additions to the WDPA has been marine, the largest national-scale additions have been in the marine realm, and the world's largest protected areas are overwhelmingly marine, all of which concurs with a growing literature reiterating this trend (Jones et al. 2011; Thomas et al. 2014). The fact that this growth has been disproportionately in Asia and the Pacific is due to a combination of large nations, such as Australia, and smaller nations, such as the Cook Islands, adding new protected areas particularly in the marine environment. Since finishing the analysis for this paper in 2016, marine coverage has increased by a further 6.5 million km^2, resulting in more marine protection than terrestrial protection for the first time in history (UNEP-WCMC 2017). The causative factors behind the terrestrial realm's plateauing coverage are poorly understood, although an obvious answer is that competing land-use pressures prohibit creating terrestrial protected areas the size of Mexico, as happened in the marine realm in July 2017 (UNEP-WCMC 2017).

However, the undisputed overall growth in the world's protected -area estate has hidden a counter flux of protected-area removal. The scale of this removal is on average over 1 million km^2/year, and this is mainly terrestrial protected area loss, although we found some of this was later reprotected. The United States has the highest negative footprint in the WDPA between 2006 and 2016. This is not because protected areas are being degazetted or downsized but because these existing sites no longer comply with the IUCN definition of a protected area and are now referred to as other managed lands (Stamper et al. 2013; NAWPA 2016). In total, this resulted in 1.3 million km^2 of terrestrial protected area in the United States being removed from the WDPA. Similarly, the expiration of a hunting ban in 2 very large (0.5 million km^2) terrestrial protected areas in Saudi Arabia led to their removal from the WDPA in 2016, a significant factor in reducing global protected-area coverage on land from 2014 to 2016.

Some of the removed area in the temporal WDPA was never a reality on the ground because it was an artifact of data quality (e.g., a buffered point in year x becoming a polygon in year $x+1$ [Supporting Information]). Omitting data when reporting to the WDPA in conjunction with data-quality problems over time assuredly accounts for some of the lost area over the years, but not all of it. Since 2004, 4.3 million km^2 from protected areas with defined boundaries have been removed from the WDPA and remain absent. As for the United States, this is not necessarily due to degazettement or downsizing, but these instances merit further investigation (Supporting Information).

The growing literature on protected-area degazettement or reduction shows that the loss of protected area is a serious threat to conservation progress (Mascia et al. 2014; Forrest et al. 2015). Other studies show that degazettement and reduction is not an uncommon occurrence and is even set to potentially increase (Bernard et al. 2014). Even some of the biggest contributors to the WDPA, such as Brazil, are not immune from reductions in their protected-area networks (Ferreira et al. 2014; McNeely 2015).

The temporal WDPA has the potential to effectively identify sites where degazettement or reduction has occurred and to track them afterward when the areas are potentially recovered by other protected areas, a phenomenon we found occurs regularly. A careful analysis of each protected area removed from the WDPA would provide a clearer picture of whether these areas are real losses or a result of low-quality data. To do this globally was outside the scope of this study, but it was undertaken for one nation to provide further evidence for the approach's utility. By matching the negative footprints of the temporal WDPA approach to proven PADDD sites in Uganda, we were able to delineate detailed boundaries of 20 protected areas that were degazetted or downsized, 60% of the nation's recorded downgraded and degazetted sites for which areas were provided (Supporting Information). Crucially, the negative footprints broadly aligned with the reported PADDD area determined with PADDD tracker.

It is possible that a negative protected-area footprint between year x and year $x+1$ may be recovered by the same protected areas returning in year $x+2$. By demonstrating that the majority of area removed from the WDPA since 2004 remained absent in 2016 (Fig. 3), we showed that protected-area turnover is not entirely due to the data churn in the WDPA monthly updates. However, because half of the negative footprints derived from buffered points, these areas would likely not be reprotected anyway.

As demonstrated between the 2010 and 2011 versions of the WDPA, when protected areas were temporarily omitted from the WDPA through national reporting of different data sets, it can create very large false negative footprints (Supporting Information), as has been found in other studies (Cook et al. 2017). This kind of flux may have occurred for some sites if the nation was uncertain of the status of a protected area or if there was a significant dispute between agencies managing protected areas in a county.

Next Steps

The predominant narrative around the development of the world's protected-area estate has until recently been one of steady and continual growth. This has been shown to be an oversimplification. Precisely delineating when and especially why reductions occur is still not entirely within reach, but it is paramount that the conservation community recognize that it can and does occur and is often hidden among a larger-scale addition of protected area. The temporal WDPA does not yet have the ability to create a wide-ranging time series; therefore, we propose that in conjunction with the existing approach, a temporal WDPA footprint approach be undertaken that can provide context to the removals or additions in globally protected areas, thus explaining, should it occur, why protected-area coverage is lower than previously recorded. The need for timely and precise reporting on protected-area coverage is going to be increasingly important when reporting conservation progress toward SDGs, within the various regional and global IPBES assessments, and the achievement of the Aichi targets within the Global Biodiversity Outlook 5 in 2020. It is therefore imperative these metrics fully reflect the dynamism demonstrated in the protected-area data in this paper.

In future work, we aim to address some of the limitations highlighted in this analysis by reducing the number of protected areas without known boundaries in the WDPA, reviewing degazettement and downsizing events picked up through national reporting to the WDPA in more detail, and collating additional versions of the WDPA in the temporal WDPA (see Supporting Information for details).

We set out to demonstrate how the WDPA changes, including where, when, and by how much, and have shown the different degrees of positive and negative flux between the terrestrial and marine realms that has resulted in 2 very different growth trajectories. It is somewhat unclear why these changes occurred. We hope the WDPA can be more fully integrated into PADDD research, especially in the context of a globally standard approach (Pack et al. 2016), although we appreciate that the WDPA still has significant caveats in analyses of this kind (Cook et al. 2017). The PADDD approach provides a good overview of why protected areas are being downgraded, downsized, and degazetted, but the message could be strengthened if PADDD could be combined with the latest spatial analyses techniques and the scale of data provided by the temporal WDPA. The temporal WDPA has enormous potential already but especially in the future because with every passing year the WDPA becomes bigger, more robust, and more accurate.

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Supporting Information

The component data for each year in the temporal WDPA (Appendix S1), positive, negative, and net footprint results for each year, (Appendix S2), proportion of each negative footprint that was reprotected by 2016 (Appendix S3), demonstration of how buffered points can create commission and omission errors in interannual footprints, (Appendix S4), demonstration of how shifting boundaries can create commission and omission errors in the interannual footprints (Appendix S5) are available online. The authors are solely responsible for the content and functionality of these materials. Queries (other than absence of the material) should be directed to the corresponding author.

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