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CONVERGENCE BETWEEN STUDIES ON ECOSYSTEM SERVICES AND NUCLEAR TECHNOLOGY - A NECESSARY APPROXIMATION

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ABSTRACT

If in the 19th-century scientific knowledge moved from a generalist perspective to a growing specialization, in recent decades, problems that transcend disciplinary and political boundaries have required solutions based on interdisciplinary research and global actions, which led to the establishment of the Sustainable Development Goals (SDGs) in 2015. In the same perspective, studies on ecosystem services emerged as an area of transdisciplinary knowledge in rapid growth, while advances in the nuclear field enabled applications in industry, health, agriculture and the environment. Considering the development of these two spheres of knowledge, the objective of this study is to evaluate the correlation between the areas of Ecosystem Services and Nuclear Science and Technology, through category building and content analysis applied to articles listed in the Web of Science. From 1980 to June 2019, 22,751 records (article and review) were listed for the term "ecosystem service*". When refining the result with the application of descriptors related to the nuclear area, correspondences were found for "Uranium"=13; "Nuclear Power"=6; "Nuclear Energy"=1; "Nuclear technolog*"=1; "Nuclear fuel*"=1; "Nuclear material*"=1, in a total of 23 correspondences only. On the other hand, the search using key descriptors of the nuclear area, plus the terms "nature" or "ecosystem*" or "environment" for the same period, totaled 9,328 papers (articles and reviews). While the NST is broadly convergent with SE, this correlation needs to be made more explicit in the studies, expanding the prospects for the conservation, preservation and recovery of the ecosystem services and their contribution to human well-being.

1. INTRODUCTION

Ecosystems are defined as a dynamic complex of plant, animal, micro-organism and inorganic (water, soil and air) communities that interact as a functional unit [1, 2]; while ecosystem services (ES) are understood to be the ecological characteristics, functions or processes that contribute directly or indirectly to human well-being, i.e. they are the benefits that people obtain from ecosystems [2 – 4].

The study on ES emerged in the 1980s and is now consolidated as a well-defined transdisciplinary area [4 – 6], with journals that deal specifically with the theme. The *Ecosystem Services Journal* stands out, being established in 2012 as an international, interdisciplinary journal that deals with the science, policy and practice of ES, defined as the direct and indirect contributions of ecosystems to human well-being. Until June 2018, the *Ecosystem Services Journal* had 757 articles published [7].

Both the concept of ES and its application were widely popularized from the works of the *Millennium Ecosystem Assessment – MA* (2001 – 2005); considered the largest scientific task force ever undertaken to evaluate the consequences of ecosystem change for human well-being (HWB) and scientific basis for action [2, 6, 8 – 10], concluded that more than 60% of ES are being degraded or transformed, putting at risk the HWB [8].

Currently, the *Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services – IPBES*, established in 2012, is the largest global effort to develop a synthesis of ES and knowledge on biodiversity [11]. For IPBES, ES were redefined as "*nature's contributions to people – NCPs*", with an approach considered a more inclusive and diverse interpretation of human-nature relations [11 – 14], of which ES would be a subset [15]. Although it is too early to evaluate the effectiveness and acceptance of the proposed redefinition of concepts made by IPBES, both for researchers and decision makers [4, 16, 17], in its pluralism, the concept embraces a range of perspectives and connects ecologists, economists and social scientists. Despite the debates regarding conceptual frameworks, evaluation methodologies, valuation and main terminology, [15,19] the concept of ES is considered operational [17], although the present study questions the establishment of this connection in relation to nuclear scientists working in the environmental field.

The concepts related to ES are useful ways of highlighting, measuring and valuing the degree of interdependence between human beings and nature, providing tools that communicate with different audiences, in order to achieve different purposes in the fields of science and public policies. In addition, the loss of these services affects both the well-being of people and development in its multiple dimensions. The promotion of the well-being of humanity and the protection of the environment are the most urgent global challenges and appear in the central ideas of the Sustainable Development Goals (SDGs).

Adopted in 2015 by the 193 member-states of the United Nations, as part of the 2030 Agenda, the 17 SDGs, with their 169 targets and 244 associated indicators were established as a new international plan of action to address the challenges of sustainable development [20 – 22]. The SDGs are action plans established to guide governments and society in finding solutions to current problems in a sustainable manner, including the challenges related to poverty, inequality, environmental degradation, prosperity, climate, peace and justice [22, 23]. Ecosystem services uphold all dimensions of the HWB, and their integration into established strategies for achieving the SDGs is crucial [23 – 28].

The use and application of nuclear science and technology (NST) are significant for the SDGs, contributing in areas such as energy, human health, food production, water resource management and environmental protection [29 – 32], with increasing participation for the conservation, evaluation or recovery of ecosystems and their services. Considering the various applications of nuclear technology and the advancement of these two fields of knowledge, the objective of this study is to evaluate the correlation between the areas of ES and NST.

2. MATERIALS AND METHODS

The data used in this study were collected between June 21 and June 25, 2019, with exploratory research in the *Scorpus* database [33] and with systematic collection in the *Web of Science* [34], for analysis of the ecosystem services theme and its relation with the area of knowledge on nuclear technologies. These databases provide a large number of peer-reviewed articles and provide different subscription levels. Restricted access was used for academics at the University of Brasilia (UnB), with the selection of publications corresponding to "*article*" and "*review*", for the period from 1980 to 25 June 2019. We retrieved records with the term "ecosystem service" or "ecosystem services" as a topic, that is, when the term appears in the title, abstract or keywords. The data collection for analysis was performed from the *Web of Science* and resulted in 22,751 records for the specified conditions. In this result, a new search was applied for the descriptors related to the nuclear area, with the application of masks, being used: "Uranium"; "Nuclear Power"; "Nuclear Energy"; "Nuclear technology*"; "Nuclear fuel*"; "Nuclear material*"; "Irradiation"; "Isotope*"; "Nuclear application*"; "Nuclear Physics*"; "Nuclear reactor*"; "Nuclear Radiation*"; "Nuclear Instrumentation*"; "Nuclear Security"; "Nuclear Research". Analyses and systematization of information made available on the site of the International Atomic Energy Agency [29] and in correlated bibliography on the applications of nuclear technologies [30 – 32, 35] were performed to establish the correlation between the two areas of knowledge.

3. RESULTS AND DISCUSSION

3.1. Ecosystem Services and Interactions with Human Well-Being

Global sustainability policies, such as the SDGs, aim to ensure sustainable development. For the operationalization of these policies, the concept of ES stands out. ES are the ecological characteristics, functions or processes that contribute directly or indirectly to the HWB, that is, they are the benefits that people obtain from ecosystems [2, 3, 28].

Although the term "*nature's services*" first appeared in the literature in 1977 [36], and "*ecosystem services*" in the 1980s [37], the idea that natural systems provide benefits that support the HWB is considered as old as humanity itself [4, 38]. However, it was from two seminal publications on ES in 1997 [3, 39] that the expansion of research and political applications of the approach [4], whose popularization and exponential trajectory is attributed to the work developed by the MA [2, 8], for presenting a holistic way to understand and evaluate the human impact on the planet and the local and regional socio-ecological dynamics [9, 10].

In 2017, a survey conducted in the *Scopus* database showed a total of more than 17,000 articles published with the term "*ecosystem services*" in the title, abstract or keywords, with more than 2,800 works in 2016 alone [4]. Within the scope of this study, similar searches were conducted in June 2019 on two scientific databases [33, 34], using as search criteria the terms "*ecosystem service*" and "*ecosystem services*" for documents such as "*article*" and "*review*"; 22,049 documents were obtained from the *Scopus* database and 22,751 records from the *Web of Science*. Figure 1 shows the results obtained in the search for publications made in the latter, by year of publication.

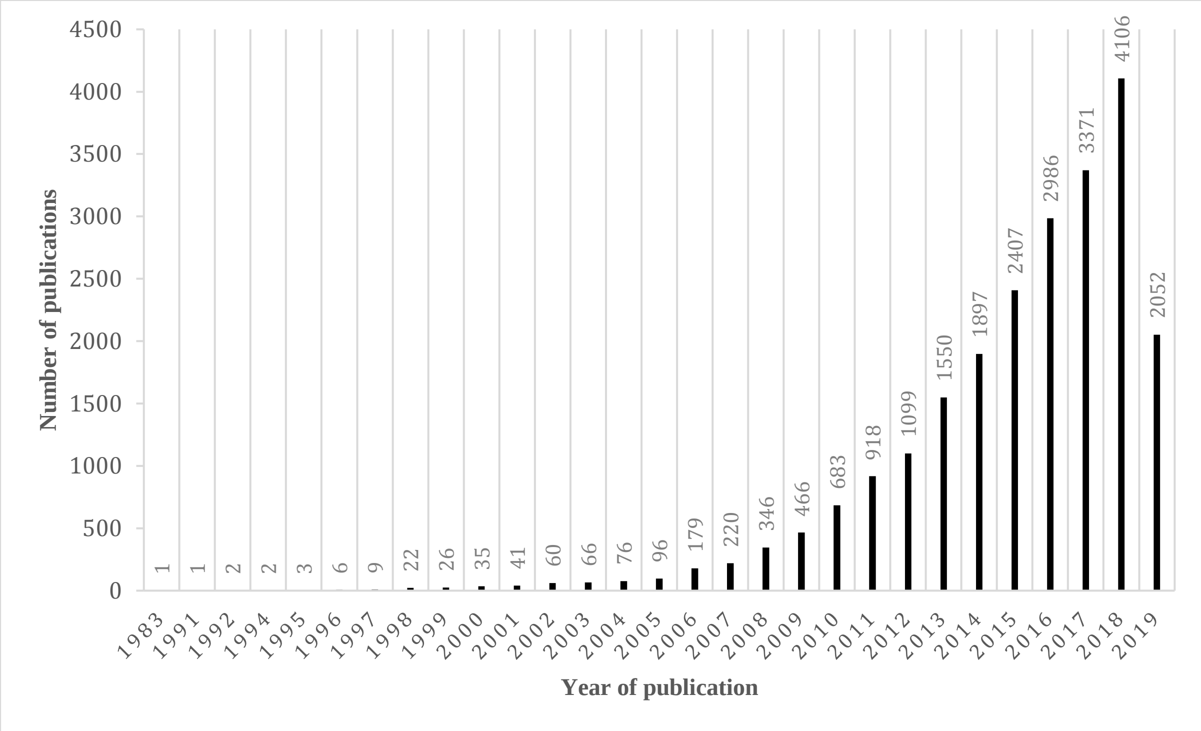

Figure 1: Growth of the area of knowledge on ecosystem services, in the period from 1983 to 2019

The rapid growth of this area of transdisciplinary knowledge on ES is due, in particular, to the urgency of problems that transcend disciplinary boundaries and that require a broader perspective to understand the complexity of the entire system and the possible solutions [5]. Since the work of the MA, the concept of ES has grown in popularity mainly due to better conditions for environmental decision-making, including multifunctional planning to understand the role of ecosystems in service delivery and analysis of how changes in land use and management may restrict the future supply of ES [10].

Although several classifications for ES have been proposed [6] for the operational purposes of this article, we opted for the categorization into functional lines presented by the MA [2], using the categories of provision, regulation, cultural, and support, illustrated in Figure 2.

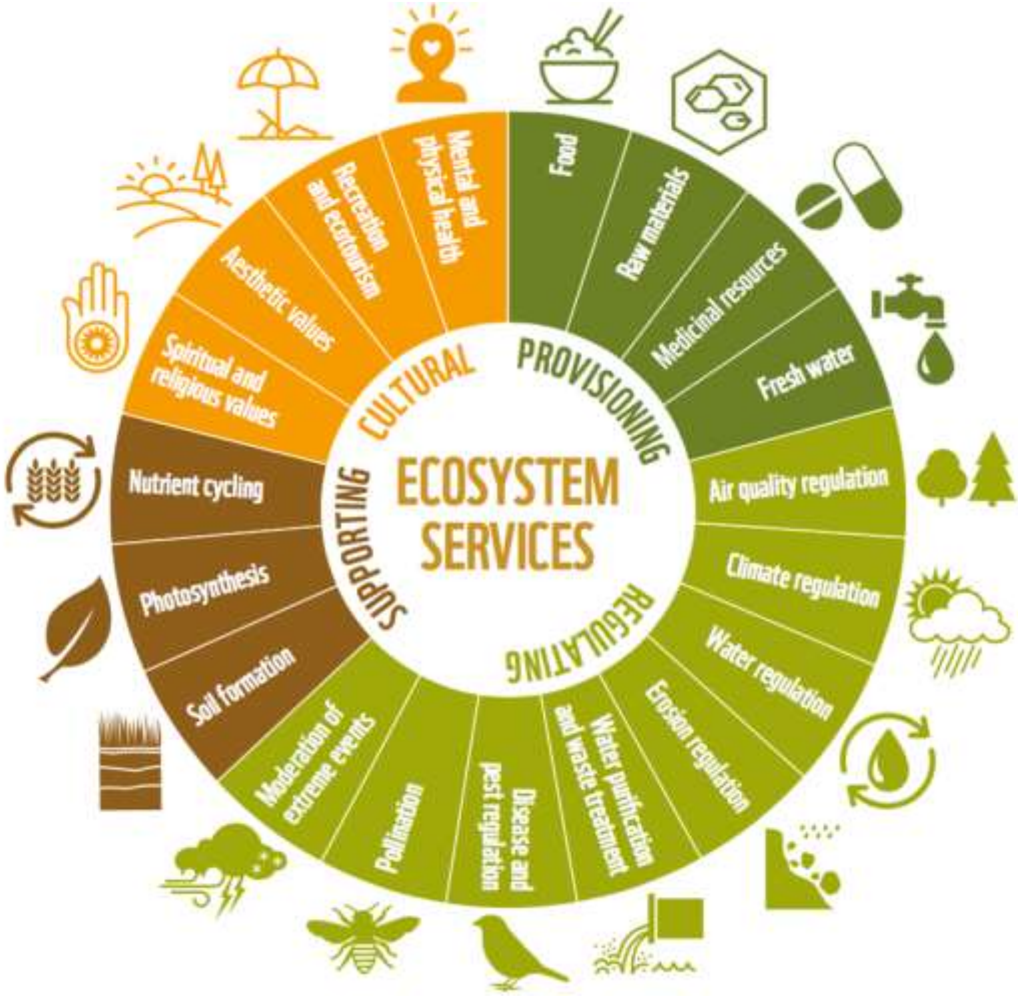

Figure 2: Ecosystem services in functional categories (provisioning, regulating, cultural and supporting services) [2, 40].

While there is a growing demand for ES, there is also an increasingly dramatic degradation of the capacity of ecosystems to provide them. The very lack of knowledge about the services provided by ecosystems constitutes one of the barriers to the protection of natural heritage. The degradation of ecosystems and the consequent change in their services directly affect the HWB, with impacts on safety, on the material goods necessary for healthy living, on health, and on social and cultural relations. These components of well-being influence people's freedom of choice and, at the same time, are influenced by them [2, 8].

The framework proposed by the MA [2] conceptualizes the links between drives that directly or indirectly affect ES and biodiversity (such as population, technology, lifestyles); changes in ecosystems and the services they provide affect the HWB. These links occur between spatial and temporal scales, and actions can be taken to respond to negative changes or to increase positive changes at almost every point of the structure (black bars) (Figure 3).

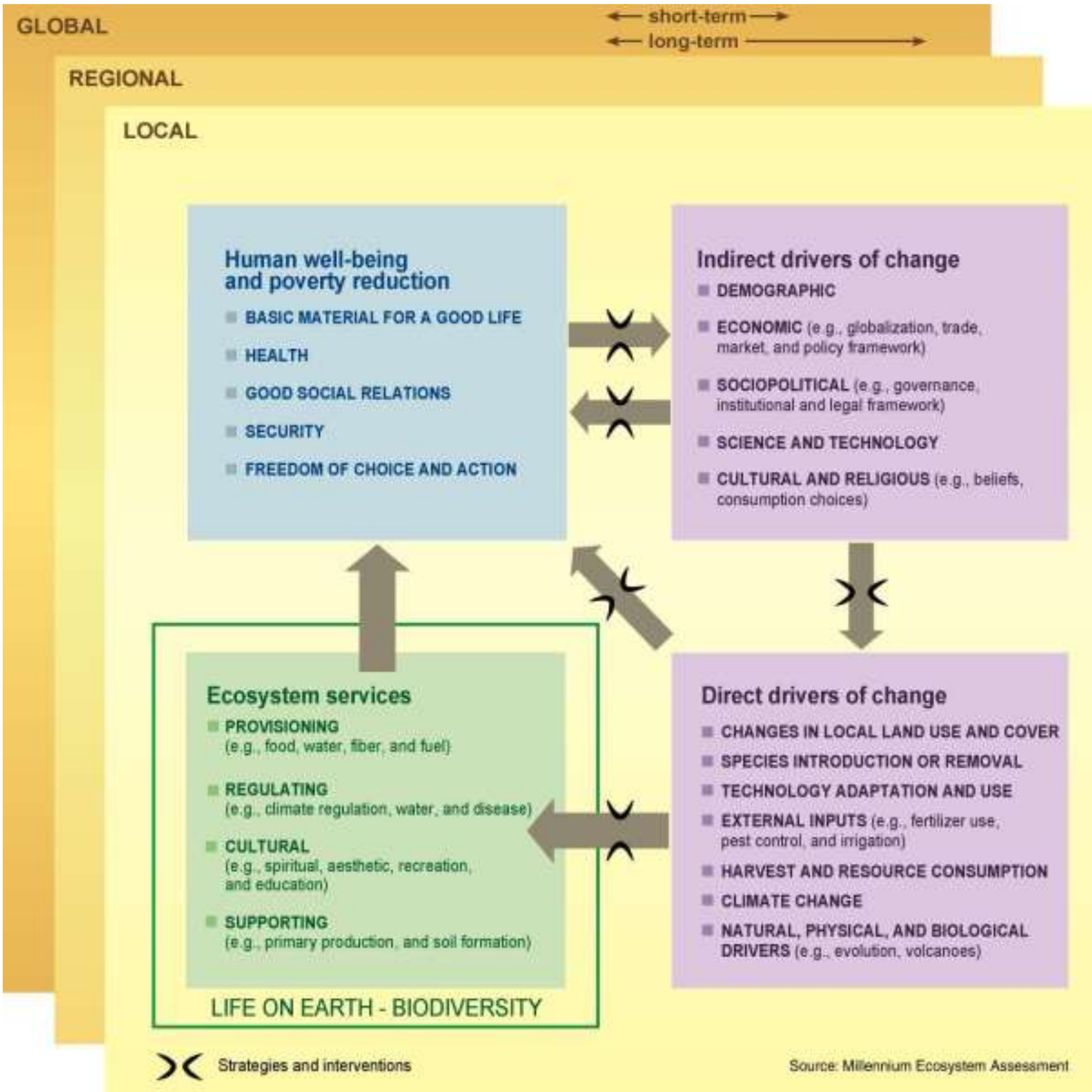

Figure 3: Conceptual structure of the Millennium Ecosystem Assessment [2].

The results of the MA point to major problems associated with the management of ecosystems and which mainly impact the poorest populations. The degradation or unsustainable use of approximately 60% (15 out of the 24) services examined stands out. These declining services include pure water, capture fishing, air and water purification, local and regional climate regulation, control of natural threats and epidemics [8]. Many services deteriorate as a result of actions taken to intensify the provision of other ES, the so-called *trade-offs*, whose management involves different objectives, values and stakeholders [2, 8, 41 – 43].

The main large-scale initiatives and projects on ES and natural capital are summarized in Table 01; although not comprehensive, they provide important input on applications related to ecosystem services.

Table 1: institutions and programs leading ES research and practice [4 - adapted]

Programs/Institutions	Description
Millennium Ecosystem Assessment (MA)	The MA was a 4-year, 1300 scientist study commissioned by the United Nations in 2005. The report analyzed the state of the world's ecosystems and provided recommendations for policymakers [8]. It determined that human actions have depleted the world's natural capital to the point that the ability of a majority of the globe's ecosystems to sustain future generations can no longer be taken for granted [44]
The Economics of Ecosystems and Biodiversity (TEEB)	In 2008, the first report of a second international study was published on The Economics of Ecosystems and Biodiversity [45], hosted by UNEP. The TEEB's primary purpose was to draw attention to the global economic benefits of biodiversity, to highlight the growing costs of biodiversity loss and ecosystem degradation, and to draw together expertise from the fields of science, economics, and policy to enable practical actions moving forward. The TEEB report was picked up extensively by the mass media, bringing ecosystem services to a broad audience [46].
Ecosystem Services Partnership	The Ecosystem Services Partnership was created in 2008, inspired by the MA and TEEB projects and has since grown to become the biggest international member-based network focused on facilitating ecosystem services research and practical applications. The network connects over 3000 ecosystem services professionals from science, policy and practice worldwide (including over 50 member-organizations) who are working together in 37 working groups, 10 regional chapters and 40+ national networks on all continents [47]
IPBES	The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services is an intergovernmental body which provides information on the state of biodiversity and ecosystem services for decision-making purposes. It was established in 2012 and current membership includes 126 countries. It is placed under the auspices of four United Nations entities: UNEP, UNESCO, FAO and UNDP [11]
EU Biodiversity Strategy to 2020	The European Union Strategy to 2020 includes the concept of ''ecosystem services", with strategic targets and actions. It includes a proposal to map and assess the state of ecosystems, their services and economic values with the goal of incorporating these values into accounting and reporting systems at EU and national level by 2010 [48]
WAVES	The Wealth Accounting and Valuation of Ecosystem Services is a World Bank-led global partnership that aims to promote sustainable development by promoting planning and national environmental and wealth accounting [49]
Natural Capital Project (NatCap)	The Natural Capital Project is a partnership between Stanford University, University of Minnesota, The Nature Conservancy, and the World Wildlife Fund with the goal of integrating the value of ecosystem services into decision making. The NatCap has developed open-source tools, such as the Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST) which models the ecosystem services values and uses [50]
Natural Capital Coalition (NCC)	The NCC was created in 2014 and it is a global multi-stakeholder organization with the goal of supporting the business community to incorporate ecosystem services and their values into their operations. The recently published the Natural Capital Protocol, a framework designed to support businesses managers decision related to their impact on the environment [51]
COMMON International Classification of Ecosystem Services (CICES)	The Common International Classification of Ecosystem Services (CICES) developed from the work on environmental accounting undertaken by the European Environment Agency (EEA). It supports their contribution to the revision of the System of Environmental-Economic Accounting (SEEA) which is currently being led by the United Nations Statistical Division (UNSD) [52]

ES *trade-offs* involve a wide and complex range of exchanges related to ecosystem use, including land-use change, management regimes, technical versus nature-based solutions, natural resource use and species management. The total cost resulting from the loss and deterioration of these services is difficult to measure, however, the evidence points to substantial and increasing values [8]. In 1997, the services provided by the ecosystems of the planet were estimated, on average, at U$ 33 trillion/year. For 2011, the estimate was that the ES would total U$ 125 trillion/year (assuming updates in the values and areas of the biomes), or U$ 145 trillion/year (considering only the updates in the values of the services). Land-use changes corresponded to the loss of ES between US$ 4.3 and US$ 20.2 trillion/year in the period from 1997 to 2011 [3, 53].

ES have entered both the media and business, including initiatives such as the partnership between *Dow Chemical* and *The Nature Conservancy - TNC* to account for the costs of the ecosystem and the benefits of each business decision, which will provide a significant addition to ES assessment knowledge and techniques. Similarly, *TruCost*, an UK-based company, evaluates the impact that publicly owned corporations have on natural capital and ES [4].

3.2. From Ecosystem Services to the Sustainable Development Goals: The Role of Nuclear Science and Technology

The safe supply of ecosystem services that contribute to the HWB is directly related to the SDGs, and information on the state of ES and their trends [28] is highly relevant to the fulfillment of the 2030 Agenda [20]. The wide range of themes addressed in the SDGs, from reducing poverty and hunger to cities, economies and sustainable ecosystems, provides a multisectoral approach, in which the reconstruction and strengthening of the integrity and function of ecosystems are related, to some degree, to all SDGs [24 – 28, 54 – 59]. Biodiversity and ES uphold all dimensions of human well-being – social, cultural and economic [2, 8, 11, 53]; however, their unsustainable exploitation compromises the achievement of the SDGs, which necessarily depend on ecosystem management for the protection and sustainable and equitable provision of their services [23, 60]. The SDGs relate to each other through their indicators, whose results contribute to the achievement of different goals. The safe supply of ES and their contribution to the HWB is the way to achieve the established goals [23].

The least developed countries and regions and the poorest people, who depend directly on access to ecosystems, are the most affected by the degradation of their services, whose constant decrease in capacity contributes to the increase in inequalities and disparities between groups and populations [8], with implications for the level of success of the SDGs, which should differ widely among countries [23, 60]. Due to the severity of the damage to the planet, the health of people will be increasingly threatened if urgent measures are not taken, highlighting that the health and prosperity of humanity are directly linked to the conditions of the environment. Of the 244 SDG monitoring indicators, 93 refer to environmental issues, so that the environmental dimension of the 2030 Agenda is configured as an entry point to promote integrated achievements of the SDGs with an impact on the economy and social aspects of sustainable development, and vice-versa [23, 60].

The 17 SDGs of the 2030 Agenda aim to stimulate action in areas of critical importance to humanity and the planet. Nuclear Science and Technology (NST) are tools for achieving the SDGs in areas such as energy, human health, food production, water resource management and environmental protection. The use of these techniques contributes directly to nine of the

17 SDGs [29; 35]. The information on the application of nuclear and isotopic tools to address environmental issues was systematized, with a focus on evaluation, recovery and conservation of ecosystem services, also considering the contribution of the NST to the identified SDGs (Table 2).

Table 2: Ecosystem Services mediated by Nuclear Science and Technology and contribution to the Sustainable Development Goals

Ecosystem Services	Contributions of NST to the SDGs and their relation to Ecosystem Services	Goal
Food (crops, livestock, aquaculture, capture fisheries); Genetic resources, Biochemicals, natural medicines, pharmaceuticals; Fresh water; Erosion Regulation; Water purification; Pest regulation; Cultural services	Conservation of soil, water and agricultural resources; protection of crops against pests; development of new varieties of plants resistant to disease and changing climatic conditions; increase in soil salinity; protection of animal health and improvement in animal breeding practices	SDG 2 Zero hunger
Water regulation Erosion regulation Climate regulation Fresh water Water purification and waste treatment Disease regulation Capture fisheries Aquaculture Cultural services	Studies on: quality and quantity of water resources; adaptation to climate change; the flow of groundwater and transport route of contaminants. Mapping the size of water resources, including groundwater reservoirs; detection and analysis of pollutants in water bodies and tracking their movement; destruction of wastewater pollutants; monitoring of critical water bodies; development of water remediation time models under different nitrate input scenarios; study of nutrient load linkages, eutrophication and increasing frequency and intensity of harmful algal blooms in freshwater; Identification of the origin (natural or anthropogenic) of increased concentrations of trace elements in groundwater and contamination of surface water exposed to air in open tanks by radionuclides; use of stable trackers and radioisotopes to identify sources of contamination and quantify the transformation and biodegradation of pollutants in aquifers; use of radiation for wastewater treatment	SDG 6 Clean water and sanitation
Climate regulation Air quality regulation	Clean, low-carbon energy	SDG 7 Affordable and clean energy
Freshwater Climate regulation Water purification and waste treatment Air quality regulation	Cleaning of wastewater and air contaminants; monitoring and tracking of construction sediments, dredging or dumping in coastal areas; use of radiation to treat nitrogen oxides (NOx) and sulfur oxides (SOx) present in combustion gases (combustion exhaust gases produced in plants), as well as effluents from the textile dye industry and to make sewage sludge suitable for application in agriculture	SDG 9 Industry, innovation and infrastructure
Freshwater Climate regulation Air quality regulation Biodiversity Crops Water regulation Water purification Natural hazard regulation	Data collection and monitoring of how climate change affects the environment; Identification of polluting sources and GHG emissions; development of crops that reduce emissions and favor CO2 capture/retention in the soil and "climate-smart" farming methods - optimization of food production in adverse weather conditions (drought and high temperatures), and for the conservation and preservation of natural resources (such as soil and water); studies of natural processes that influence the global dissemination of pollutants and their deposition rates on land and sea; monitoring of GHG routes and other pollutants in the atmosphere, their distribution and impacts on ecosystems, in terrestrial and marine environments; development of models to predict changes in the global carbon cycle and the climate	SDG 13 Climate action
	Tracking and monitoring of contaminants in marine	

Ecosystem Services	Contributions of NST to the SDGs and their relation to Ecosystem Services	Goal
Spiritual and religious values Aesthetic values Recreation and ecotourism Climate regulation Water regulation Water purification and wast treatment Genetic resources Capture fisheries	environments, such as microplastics, radionuclides and heavy metals; studies on how contaminants affect marine organisms and ecosystems, seafood quality and contaminant transfer in the food chain; studies on ocean acidification and its consequences on marine life and ecosystems; identification of ways to protect the ocean and coastal communities; radiolabeled tracers for studies of how microplastics are contaminated by organic pollutants and how they transfer such contaminants to marine organisms; study of natural archives (sediment cores, corals and shells) for evaluation of accumulation rates of contamination in coastal and marine ecosystems and historical analysis of pollution incidents in these ecosystems	SDG 14 Life below water
Spiritual and religious values Aesthetic values Crops Fresh water Biochemicals, natural medicines, pharmaceuticals Erosion regulation Pollination Genetic Resources	Development of efficient methods of soil management, soil conservation and crop production, with the possibility of reversing erosive processes and avoiding degradation of water resources; identification of isotopes in different contaminants (such as chemical fertilizers or industrial pollutants) to measure their concentration and trace their source; Restoration of radiation-contaminated areas, including uranium production sites; Use of nuclear and isotopic tools to study the impact and movement of pollutants in terrestrial environments and the compromise of ecosystem services	SDG 15 Life on land

Although the systematization presented in Table 2 is not exhaustive, it presents a very comprehensive set of correlations between SDGs, ES and NSC. The data was obtained from the analysis of official records of the International Atomic Energy Agency, available on its website and in its publications [29 – 32, 35]. The direct connection between the services provided by ecosystems and the challenges for achieving the SDGs considers the dependence that humanity and its development have on ecosystems. This interaction is influenced by factors such as population growth, change in age distribution, distribution of wealth, consumption patterns and displacement (planned and unplanned migration). The connections established in Table 2 show that this interaction contributes directly to achieving SDGs 2, 6, 7, 9, 13, 14 and 15 (zero hunger; clean water and sanitation; affordable and clean energy; industry, innovation and infrastructure; climate action; life below water; life on land).

Tools based on nuclear science are used to study terrestrial and aquatic systems. Stable isotopes and nuclear techniques are used to assess freshwater resources, biological systems, atmospheric processes and ocean ecosystems, as well as to improve agricultural practices; to assess impacts on the environment, particularly the fingerprint of natural and anthropic pollution and to study the processes in which pollutants become integrated into biological, geological and chemical cycles [29, 32].

Nuclear technologies provide solutions to help tackle hunger and malnutrition and improve environmental sustainability. In India, for example, sheep farming is important for the livelihoods of family farmers and landless people and is one of the main economic activities. As sheep normally produce only one lamb per birth, a systematic marker breeding program has been developed to increase prolificity in local sheep. Positive results in reproductive efficiency and the rate of twinning in sheep herds benefit smallholder farmers with additional lambs added at each breeding season. In Africa, (Figure 3) cassava cultivation using methods improved in nuclear science and related techniques triple productivity. The application of nitrogen isotope allows quantification of the precise amount of fertilizer to be used and at what stage of the plant's life cycle and how to incorporate locally available manure as an additional nutrient. Isotopic techniques are also used to determine the amount of water that cassava needs to develop and minimize waste [29].

Figure 3: Application of nuclear technology for food supply and human well-being in Africa [29].

Water security, which includes the availability of ecosystem services, their quality, management and protection, is a critical issue for human development, environmental and economic sustainability; and access to water is critical for meeting human needs, for food and energy production, for industry and for environmental protection. Nuclear isotopic techniques provide important information on water sources and the human impact on the climate [29, 32]. Land-based sources account for about 77% to 100% of marine pollution, including heavy metals, persistent organic pollutants, pathogens, radioactive substances, hydrocarbons, petrochemicals, plastics and other forms of solid waste, heat and noise [35].

Nuclear and isotopic techniques are used to understand and propose mitigation strategies and tools for the environmental impacts of radionuclides, heavy metals, trace elements and organic contaminants, as well as for climate change, habitat destruction and biodiversity loss in the marine environment, and radiopharmaceutical applications for environmental pollution. Still focused on the marine environment, pollution assessments are carried out to improve the safety of seafood, and stable isotopic techniques are applied to study pollution processes and sources of fingerprint pollutants [35].

The environmental dimension of sustainability reinforces the vital connection of ecosystems and their services with human society and its development, expressed in its multiple dimensions in the SDGs. Although the studies on ES and NST are correlated, NST's contributions are not being incorporated into ecosystem services as an area of knowledge, as shown in Table 3.

The studies on the application of nuclear technology to environmental issues, mapped in this exploratory research from official documents and information of the International Atomic Energy Agency (IAEA) [29 – 32, 35], showed its factual and concrete relevance for the conservation, recovery and evaluation of ecosystem services. However, in the studies on ecosystem services, the use of nuclear techniques was timidly identified - for more than 22 thousand papers (articles and reviews, since 1980), there was correspondence for only 23 studies, which represents 0.10% of the papers. On the other hand, by systematizing nuclear publications for the same descriptors and filters (articles and review since 1980), more than 700 thousand results were found. In an attempt to approximate, the results for each descriptor were refined with the use of the expressions <"ecosystem*" and "nature" or "water resource*">; in its entirety, this new research resulted in 1,307 studies. Nuclear-related publications were again systematized to apply the expressions <"ecosystem*" or "nature" or "environmental">. In this last selection, more than 58 thousand records were located, and 9,328 were published in the "Environmental Sciences" category.

Table 3. NST's contribution to the development of the field of knowledge of ecosystem services

Key-words used	Nuclear Science and Technology Area				Ecosystem Services Area[2]
	Number of papers	Refined results using the expression		Refined results Environmental Sciences[1]	Refined results for key-works NST area
		<"ecosystem*" and "nature" or "water resource*">	<"ecosystem*" or "nature" or "environmental">		
"Uranium"	45.017	70	5.051	1.323	13
"Nuclear Power"	22.315	41	2.644	742	6
"Nuclear Energy"	5.155	14	775	168	1
"Nuclear technology*"	1.119	1	143	22	1
"Nuclear fuel*"	9.140	5	821	192	1
"Nuclear material*"	2.264	--	182	37	1
"Irradiation"	346.203	89	15.772	1.608	--
"Isotope*"	251.343	1.074	32.098	5.110	--
"Nuclear application*"	670	--	42	2	--
"Nuclear Physic*"	5.151	1	241	8	--
"Nuclear reactor*"	9.157	11	540	90	--
"Nuclear Radiation*"	872	--	55	1	--
"Nuclear Instrumentation*"	126	--	8	--	--
"Nuclear Security"	282	--	19	6	--
"Nuclear Research"	1.621	1	91	19	--
TOTAL OF RECORDS	**700.435**	**1.307**	**58.482**	**9.328**	**23**

Source: Prepared based on the search engine available on the Web of Science database, on 25 June 2019. Note: [1]Papers listed in the Web of Science Category "Environmental Sciences" from the refined results for the terms "ecosystem" or "nature" or "environmental". [2]Total number of papers with the term "ecosystem service*" = 22,751.

Increased collaboration, both between academic disciplines and between the Academy and the wider society, is fundamental for the development of research and practice of ecosystem services, especially when it is observed that even the IPBES, which carries out a great interdisciplinary work effort, has its base dominated by natural scientists [17]. Although the verification carried out does not include content analysis of selected papers to identify a more precise indicator on those that, in fact, could contribute to the state of the art on ecosystem services, the results presented here are very relevant, especially for indicating gaps in knowledge and integration and cooperation among researchers from different, but correlated areas. These results highlight the relevance of inter and transdisciplinary research for the development of appropriate processes for the production of knowledge in ES [17].

3. CONCLUSIONS

The theme of ES is a well-established area of knowledge that presents rapid growth, with assessments being developed on global and regional scales by various initiatives, institutions and researchers, especially IPBES. In these evaluations, as in the case of the IPCC, no new research is produced, but the available knowledge is systematized, aiming at responses that are sought. In this context, it is possible that this "invisibility" of NST-related studies may leave knowledge gaps in ES assessments or lead to partial results if they are not in fact being considered in assessments.

As relevant as this hypothesis is the evidence that the field of knowledge on ES disregards important contributions to its development from the NST. If, on the one hand, the information made available by the IAEA shows clear interfaces of nuclear applications to ES, on the other hand, only 23 papers with nuclear-related descriptors were identified in about 23 thousand publications on ES. Complementary studies to measure the existing gap are necessary and urgent. Depending on their size, the incorporation of these "new" studies that were "invisible" can promote a significant advance in a short space of time in the field of ecosystem services, in addition to integrating NST scientists who develop investigations related to ecosystems and their services but who may be on the margins of this research network.

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REFERENCES

1. UN-CBD. Convention on Biological Diversity. <https://www.cbd.int/doc/legal/cbd-en.pdf> (1992)
2. MILLENNIUM Ecosystem Assessment. Ecosystems and human well-being: a framework for assessment. Word Resources Institute (2003).
3. COSTANZA, R. et al. “The value of the world's ecosystem services and natural capital”. Nature, **v. 387**, n. 6630, p. 253 (1997)
4. COSTANZA, R. et al. “Twenty years of ecosystem services: how far have we come and how far do we still need to go?” Ecosystem Services, **v. 28**, p. 1-16 (2017).
5. COSTANZA, R.; KUBISZEWSKI, I. “The authorship structure of “ecosystem services” as a transdisciplinary field of scholarship”. Ecosystem Services, **v. 1**, n. 1, p. 16-25 (2012).
6. LA NOTTE, A. et al. “Ecosystem services classification: a systems ecology perspective of the cascade framework.” Ecological indicators, **v. 74**, p. 392-402 (2017).

7. ECOSYSTEM SERVICES. Ecosystem Services: Science, Policy and Practice. Elsevier. <https://www.journals.elsevier.com/ecosystem-services>
8. MILLENNIUM Ecosystem Assessment. Ecosystems and Human Well Being: Synthesis. Island Press (2008).
9. UN-CBD. Convenio sobre la Diversidad Biológica. Repercusiones de las conclusiones de la Evaluación de los Ecosistemas del Milenio para la labor futura del Convenio. Órgano Subsidiario de Asesoramiento Científico, Técnico y Tecnológico. Duodécima Reunión.: UNESCO, Paris, 2-6 de julio de 2007, (UNEP/CBD/SBSTTA/12/4) (2007).
10. BENNETT, E. M. "Research frontiers in ecosystem service science". Ecosystems, **v. 20**, n. 1 (2017).
11. IPBES. Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. <https://www.ipbes.net/ > (2019).
12. Díaz, S., et al. "Assessing nature's contributions to people". Science **359(6373)**:270-272 (2018).
13. Díaz, S., S. et al. "The IPBES conceptual framework - connecting nature and people." Current Opinion in Environmental Sustainability **14**:1-16 (2015).
14. PASCUAL, U. et al. "Valuing nature's contributions to people: the IPBES approach". Current Opinion in Environmental Sustainability, **v. 26**, p. 7-16 (2017).
15. Díaz, et al. "RE: There is more to nature's contributions to people than ecosystem services - a response to de Groot et al". Science E-Letter, 12 March. [online]. <http://science.sciencemag.org/content/359/6373/270/tab-e-letters> (2019)
16. Faith, D. P. Avoiding paradigm drifts in IPBES: reconciling "nature's contributions to people," biodiversity, and ecosystem services. Ecology and Society **23(2)**:40 (2018).
17. AINSCOUGH, Jacob et al. "Navigating pluralism: Understanding perceptions of the ecosystem services concept. Ecosystem Services", **v. 36**, p. 100892, 2019.
18. Spake R, et al. "Unpacking ecosystem service bundles: Towards predictive mapping of synergies and trade-offs between ecosystem services". Global Environmental Change. **47** (2017)
19. MAES, J.; BURKHARD, B.; GENELETTI, D. "Ecosystem services are inclusive and deliver multiple values. A comment on the concept of nature's contributions to people". One Ecosystem, **v. 3**, p. e24720, (2018).
20. UNITED NATIONS Development Programme. Transforming our World: The 2030 Agenda for Sustainable Development. Outcome Document for the UN Summit to Adopt the Post-2015 Development Agenda: Draft for Adoption. New York. (2015). (2015).
21. UN-SUSTAINABLE DEVELOPMENT GOALS Knowledge Platform. <https://sustainabledevelopment.un.org/ > (2019).
22. UNITED NATIONS. Sustainable Development Goals. <https://www.un.org/sustainabledevelopment/sustainable-development-goals/>. (2019).
23. LUCAS, P., et al. Future Developments Without Targeted Policies Chapter 21 - Global Environment Outlook (GEO-6): Healthy Planet, Healthy People (2019).
24. WARD, M. et al. "Food, money and lobsters: Valuing ecosystem services to align environmental management with Sustainable Development Goals". Ecosystem Services, **v. 29**, p. 56-69 (2018)
25. WOOD, S. L. R et al. "Distilling the role of ecosystem services in the Sustainable Development Goals". Ecosystem services, **v. 29**, p. 70-82 (2018).
26. DANGLES, O.; CASAS, J. "Ecosystem services provided by insects for achieving sustainable development goals". Ecosystem services, **v. 35**, p. 109-115 (2019).
27. ANDERSON, Christopher B. et al. "Determining nature's contributions to achieve the sustainable development goals." Sustainability Science, **v. 14**, n. 2, p. 543-547, (2019).
28. GEIJZENDORFFER, I. R. et al. "Ecosystem services in global sustainability policies". Environmental Science & Policy, **v. 74**, p. 40-48. 25 (2017).
29. IAEA. International Atomic Energy Agency. <https://www.iaea.org > (2019).
30. IAEA. International Atomic Energy Agency. Climate change and nuclear power (2018).
31. IAEA. International Atomic Energy Agency. Nuclear Power and Sustainable Development (2018).
32. IAEA. International Atomic Energy Agency. IAEA Technical Cooperation Programme: Sixty years and beyond – Contributing to development: Proceeding of an International Conference

organized by the International Atomic Energy and Held in Vienna, 30 May-1 June 2017: Proceedings Series, IAEA, Vienna (2018).
33. SCORPUS Database. < https://www.scopus.com/ > (2019)
34. WEB OF SCIENCE Datebe. < https://www.webofknowledge.com/ > (2019).
35. UNITED NATIONS Environment Programme. The IAEA Environment Laboratories: Supporting Member States in the Protection of the Marine Environment from Land-based Activities. Intergovernmental Review Meeting on the Implementation of Global Programme of Action for the Protection of Marine Environment from Land-based Activities. Fourth session, Bali, Indonesia, 31 October and 1 November 2018
36. WESTMAN, Walter E. "How much are nature's services worth?" Science, **v. 197**, n. 4307, p. 960-964, (1977).
37. EHRLICH, P. R.; MOONEY, H. "Extinction, substitution, and ecosystem services." BioScience, **v. 33**, n. 4, p. 248-254 (1983).
38. GÓMEZ-BAGGETHUN, E. et al. "The history of ecosystem services in economic theory and practice: from early notions to markets and payment schemes". Ecological economics, **v. 69**, n. 6, p. 1209-1218. (2010).
39. DAILY, G. C. et al. Nature's services. Island Press, Washington, DC (1997).
40. WWF. Living Planet Report - 2018: Aiming Higher. Grooten, M. and Almond, R.E.A.(Eds). WWF, Gland, Switzerland (2018).
41. CAVENDER-BARES, J., S. POLASKY, E. KING, and P. BALVANERA. "A sustainability framework for assessing trade-offs in ecosystem services". Ecology and Society **20(1)**: 17 (2015).
42. DAW, T. M. et al. "Evaluating taboo trade-offs in ecosystems services and human well-being." Proceedings of the National Academy of Sciences, **v. 112**, n. 22, p. 6949-6954 (2015).
43. TURKELBOOM, F. et al. "When we cannot have it all: Ecosystem services trade-offs in the context of spatial planning". Ecosystem services, **v. 29**, p. 566-578 (2018).
44. MILLENNIUM Ecosystem Assessment. < https://www.millenniumassessment.org/en/index.html > (2019).
45. TEEB. The Economics of Ecosystem & Biodiversity: An Interim Report. A Banson Production, Cambridge, UK (2008).
46. TEEB. The Economics of Ecosystems & Biodiversity. < http://www.teebweb.org/ > (2019).
47. ESP Ecosystem Services Partnership. <https://www.es-partnership.org/> (2019).
48. EUROPEAN COMMISSION. Environment. Nature and Biodiversity. Biodiversity Strategy http://ec.europa.eu/environment/nature/biodiversity/strategy/> (2019).
49. Wealth Accounting and Valuation of Ecosystem Services – Waves < https://www.wavespartnership.org/ > (2019).
50. NATURAL Capital Project. <https://naturalcapitalproject.stanford.edu/> (2019).
51. NATURAL Capital Coalition. <https://naturalcapitalcoalition.org/>. (2019).
52. COMMON International Classification of Ecosystem Services – CICES. < https://cices.eu/ > (2019).
53. COSTANZA, Robert et al. "Changes in the global value of ecosystem services". Global environmental change, **v. 26**, p. 152-158, (2014).
54. IPBES. Summary for policymakers of the global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services - ADVANCE UNEDITED VERSION – 6 May (2019). < https://www.ipbes.net/system/tdf/spm_global_unedited_advance.pdf?file=1&type=node&id=35245>
55. ICSU, ISSC. Review of the sustainable development goals: The science perspective. Paris: International Council for Science (ICSU) (2015).
56. ESPA. An environment for wellbeing: Pathways out of poverty – Policy messages from the ESPA Programme. Edinburgh: Ecosystem Services for Poverty Alleviation (2018).
57. LEAL FILHO, W. et al. "Reinvigorating the sustainable development research agenda: the role of the sustainable development goals (SDG)". International Journal of Sustainable Development & World Ecology, **v. 25**, n. 2, p. 131-142, (2018).
58. NILSSON, M et al. "Mapping interactions between the sustainable development goals: lessons learned and ways forward". Sustainability science, **v. 13**, n. 6, p. 1489-1503, (2018).

59. COSTANZA, R. et al. “Modelling and measuring sustainable wellbeing in connection with the UN Sustainable Development Goals.” Ecological Economics, **v. 130**, p. 350-355, 2016.
60. UNITED NATIONS Environment Programme. Measuring Progress: Towards Achieving the Environmental Dimension of the SDGs. (2019).