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Scientists as Stakeholders in Conservation of Hydrothermal Vents

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Abstract: *Hydrothermal vents are deep-sea ecosystems that are almost exclusively known and explored by scientists rather than the general public. Continuing scientific discoveries arising from study of hydrothermal vents are concommitant with the increased number of scientific cruises visiting and sampling vent ecosystems. Through a bibliometric analysis, we assessed the scientific value of hydrothermal vents relative to two of the most well-studied marine ecosystems, coral reefs and seagrass beds. Scientific literature on hydrothermal vents is abundant, of high impact, international, and interdisciplinary and is comparable in these regards with literature on coral reefs and seagrass beds. Scientists may affect hydrothermal vents because their activities are intense and spatially and temporally concentrated in these small systems. The potential for undesirable effects from scientific enterprise motivated the creation of a code of conduct for environmentally and scientifically benign use of hydrothermal vents for research. We surveyed scientists worldwide engaged in deep-sea research and found that scientists were aware of the code of conduct and thought it was relevant to conservation, but they did not feel informed or confident about the respect other researchers have for the code. Although this code may serve as a reminder of scientists' environmental responsibilities, conservation of particular vents (e.g., closures to human activity, specific human management) may effectively ensure sustainable use of vent ecosystems for all stakeholders.*

Keywords: code of conduct, deep sea, hydrothermal vents, knowledge value, scientific activities

Científicos como Actores en la Conservación de Fuentes Hidrotermales

Resumen: *Las fuentes hidrotermales son ecosistemas de mar profundo que casi son conocidas y exploradas exclusivamente por científicos en lugar del público en general. Los constantes descubrimientos científicos que surgen del estudio de las fuentes termales son concomitantes con el incremento en el número de cruceros científicos que visitan y muestrean fuentes hidrotermales. Mediante un análisis bibliométrico, examinamos el valor científico de las fuentes hidrotermales en relación con 2 de los ecosistemas marinos mejor estudiados, arrecifes de coral y praderas de pastos marinos. La literatura científica sobre fuentes hidrotermales es abundante, de alto impacto, internacional e interdisciplinaria y es comparable en estos aspectos con la literatura de dos de los ecosistemas marinos más estudiados, arrecifes de coral y praderas de pastos marinos. Los científicos pueden afectar a las fuentes hidrotermales porque sus actividades son intensas y se concentran espacial y temporalmente en estos sistemas pequeños. El potencial de efectos no deseables derivados de iniciativas científicas motivó la creación de un código de conducta para el uso benigno, ambiental y científicamente, de las fuentes hidrotermales para investigación. Entrevistamos a científicos de todo el mundo involucrados en investigación de mares profundos y encontramos que los científicos tenían conocimiento del código de conducta y pensaban que era relevante para la conservación, pero no se sentían informados o confiados sobre el respeto de otros*

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investigadores hacia el código. Aunque este código puede servir como recordatorio de las responsabilidades ambientales de los científicos, la conservación de fuentes particulares (e.g., cierre a actividades humanas, manejo humano específico) puede asegurar el uso sustentable efectivo de los ecosistemas de fuentes por todas las partes interesadas.

Palabras Clave: actividades científicas,, ódigo de conducta, fuentes hidrotermales, mar profundo, valor de conocimiento

Introduction

Hydrothermal vents are deep-sea ecosystems that are patchily distributed in time and space along spreading mid-oceanic ridges, back-arc basins, volcanic arcs, and active seamounts (Tyler et al. 2003). These ecosystems, discovered within the past 35 years (Lonsdale 1977; Corliss et al. 1979), are fueled by chemosynthesis, wherein bacteria provide the energy and organic matter to the food web in vent ecosystems and allow the existence of benthic communities characterized by high biomass and endemism (Van Dover 2000).

Although the deep sea is often perceived as one of the last frontiers on the Earth, humans now conduct different activities at hydrothermal vents. Within the last 10 years, deep-sea tourism has become established at certain vent fields (Leary 2007), and exploration has begun to measure the potential for extraction of the massive stores of sulfides in deep-sea vents that are enriched with copper, zinc, lead, silver, gold, and barium (Scott 2001; Davies et al. 2007). Currently, the primary and expanding activities in vent systems are scientific (Glowka 2003), and hydrothermal vents are sometimes considered as one of the most important biological discoveries of the past century (Dando & Juniper 2001).

The combination of scientific discoveries and the increasing number of scientific sampling expeditions to hydrothermal vents has raised the question of whether conservation measures at deep-sea vents might be warranted. Scientists may be altering these ecosystems through their work, and as stakeholder, scientists recognize their responsibilities for conserving hydrothermal vents (Mullineaux et al. 1998). InterRidge, an international, nonprofit organization of some 2000 scientists from over 27 countries who engage in midocean ridge research, facilitates international cooperation and collaboration and builds consensus on key policy issues related to scientific explorations of hydrothermal vents. The *InterRidge Statement of Commitment to Responsible Research Practices at Deep-Sea Hydrothermal Vents* (ISRRP) was one of the first steps toward sustainable use of hydrothermal vents by scientists (Devey et al. 2007). The aim of the ISRRP was to ensure scientifically and environmentally sustainable use of hydrothermal vents through the application of the following guidelines: (1) "avoid, in the conduct of scientific research, activities that will have deleterious impacts on the sustainability of populations of hydrothermal vent organisms," (2) "avoid, in the conduct of scientific research, activities that lead to long lasting and significant alteration and/or visual degradation of vent sites," (3) "avoid collections that are not essential to the conduct of scientific research," (4) "avoid, in the conduct of scientific research, transplanting biota or geological material between sites," (5) "familiarize yourself with the status of current and planned research in an area and avoid activities that will compromise experiments or observations by other researchers" and "[a]ssure that your own research activities and plans are known to the rest of the international research community through InterRidge and other public-domain databases," and (6) "facilitate the fullest possible use of all biological, chemical, and geological samples collected through collaborations and cooperation among the global community of scientists."

We examined the relation between the scientific community and deep-sea hydrothermal vent ecosystems. We addressed three issues: the value of hydrothermal vents for the global scientific community; whether there is evidence that the concentration of scientific activities may have deleterious effects on hydrothermal vents; and how sustainable scientific use of hydrothermal vents might be ensured.

We conducted a bibliometric analysis to assess the scientific value of hydrothermal vents relative to two of the most well-studied marine ecosystems, coral reefs and seagrass beds. We assessed the evolution in time and space of scientific expeditions to hydrothermal vents as a proxy of the potential pressures on these ecosystems. We surveyed scientists worldwide who study deep-sea ecosystems to determine their awareness of and attitudes toward the ISRRP. We asked scientists to suggest improvements to ISRRP that might increase its efficacy as an environmental management tool.

Methods

Knowledge Value of Vent Research

The valuation of the "knowledge value" of nature and the consideration of nature as a "living library" is often restricted to the discovery of compounds that can be used as therapeutic agents in medicine (e.g., Heal 1999; Acebey et al. 2008). Here, we consider the "knowledge value" of nature to be the contribution of any natural system to scientific knowledge. We assessed global knowledge obtained from the study of hydrothermal vents through a bibliometric analysis of scientific literature from 1977 (year first article on communities at hydrothermal vents was published [Lonsdale 1977]) through 2008. We considered the bibliometric data on hydrothermal vent research in the context of coral reefs and seagrass beds. We searched for articles and reviews in ISI Web of Science (ISIWS) that included the following terms: *hydrothermal vent**, *coral reef**, and *seagrass**. We used the "analyse results" function available in ISIWS to analyze the distribution of authors' country affiliation and the subject areas of the publications and *Journal Citation Report 2009* to evaluate the impact factors of the publications. In addition to the number of subject areas attributed or related to citations for each ecosystem, we used a Shannon index (Shannon 1948) to estimate the subject-area diversity. We used Kruskal–Wallis tests to assess differences in mean impact factors and mean number of citations between each ecosystem.

Spatial and Temporal Concentration of Scientific Cruises at Hydrothermal Vents

We used the InterRidge Cruise database (available from http://www.interridge.org/IRcruise) to determine the number and the location of scientific cruises to hydrothermal vents from 1976 to 2009. Hydrothermal vents are studied at three different spatial extents: habitats, patches of a few square meters in which physical and biological characteristics are homogeneous, but different from those of the surrounding area (e.g., a bacterial mat, a clam bed); sites, areas of >2 km^2 with several types of habitats that are geographically constrained and closely interlinked and often correspond to a prominent geological structure (e.g., the Eiffel Tower site and the Statue of Liberty in the vent field Lucky Strike); and fields, areas greater than several square kilometers composed of a collection of sites. We mapped all sites reported in the InterRidge Vents Database and superimposed them on a data layer of cruise locations in a geographic information system.

Awareness and Perception of the ISRRP

To assess the response of the scientific community to the 2006 ISRRP, we surveyed scientists working on hydrothermal vents. We used an approved protocol that complied with the Research with Human Subjects Protection Program of Duke University. (The survey form is available online [Supporting Information]). We asked for demographic information and information on research discipline, study area, and knowledge of the existence of the ISRRP (i.e., background data). We also asked respondents for their opinions on the use and efficacy of the ISRRP guidelines (e.g., Do you follow the guidelines? Do others follow the guidelines? Are the guidelines necessary? Are the guidelines easy to follow? Did you change your behavior in response to the guidelines?). In our analyses, guideline 5 had two parts : 5a, familiarize oneself with the status of current and planned research in an area and assure one's own research activities and plans are known to the rest of the international community through InterRidge and other public domain databases, and 5b, avoid activities that will compromise experiments or observations of other researchers. We contacted over 3000 members of the following professional communities who routinely engage in deep-sea research: InterRidge, participants in the 11th International Deep-Sea Biology Symposium and the 2009 international symposium Issues Confronting the Deep Ocean, and all members of Muséum National d'Histoire Naturelle and Ifremer in France. Additionally, we advertised the survey on the InterRidge and the Centre National de la Recherche Scientifique (CNRS) websites. The survey was accessible online from 15 February to 26 March 2010.

Statistical Analyses and Mapping

We performed all statistical analyses with R (version 2.10.0; R Development Core Team 2009). We generated maps with Arcview GIS 3.1. (ESRI, Redlands, California, U.S.A.) and exported the maps to Adobe Illustrator 10 (Adobe Systems, San Jose, California, U.S.A.).

Results

Knowledge Value of Hydrothermal Vent Research

From 1977 to 2008 there were fewer articles published with *hydrothermal vents* as a keyword ($n = 2631$) than articles with *coral reefs* ($n = 6774$) or *seagrass beds* ($n = 4266$) as a keyword. The number of scientific articles on each of these ecosystems increased dramatically after 1990, and the number decreased from coral reefs (700 publications in 2010) to seagrass beds (350 publications in 2010) to hydrothermal vents (225 publications in 2010) (Fig. 1).

Between 1977 and 2008, scientists from 75, 95, and 117 countries published work on hydrothermal vents, seagrass beds, and coral reefs respectively (Fig. 2). Authors from North America and Western Europe dominated the literature. Authors from Russia, East Asia, Oceania, South Africa, Mexico, South America, other African countries, and Southeast Asia also contributed publications on hydrothermal vents, and these authors had no or few collaborations with authors from other countries or regions. A similar distribution of the countries of authors was found for publications on coral reefs and seagrass beds, although a greater proportion of authors working in these ecosystems were from tropical countries (Fig. 2).

The number of subject areas in the ISIWS database was lower for the hydrothermal vent literature than for the

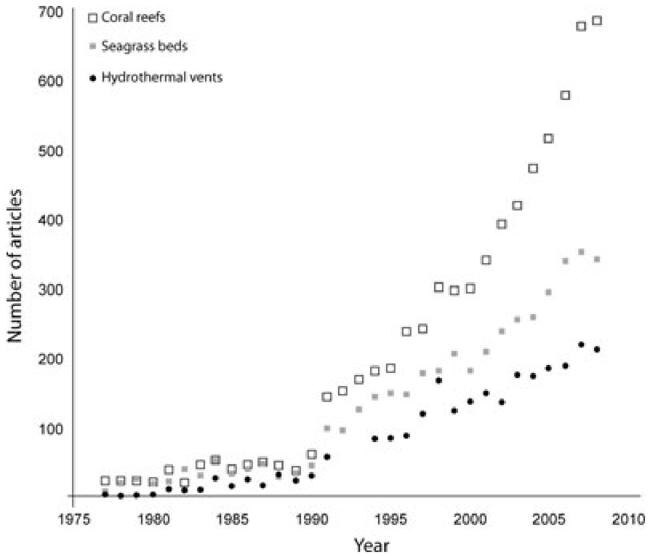

Figure 1. Number of articles per year on hydrothermal vents compared with articles on coral reefs and seagrass beds (all articles published in peer-reviewed journals and referenced in ISI Web of Science from 1977 to 2008).

seagrass bed and coral reef literature (90 subject areas for hydrothermal vents, 142 for coral reefs, 91 for seagrass beds), but there was greater evenness of abundance among subject area for hydrothermal-vent literature ($H' = 3.02$) than for coral reef ($H' = 2.84$) or seagrass bed ($H' = 2.24$) literature. Among the 20 most common subject areas in the hydrothermal-vent literature, the greatest number of publications were on microbiology, marine and freshwater biology, oceanography, geophysics, and geochemistry. In contrast, subject areas in the coral reef and seagrass bed literature were dominated by marine and freshwater biology, ecology, oceanography, and environmental sciences.

Overall, publications on hydrothermal vents were published in high-impact journals and were highly cited. The mean journal impact factor of published articles on hydrothermal vents (3.40) was significantly higher than the impact factor of published articles on coral reefs (2.77) and seagrass beds (1.99) (Kruskal–Wallis test, $p < 0.05$; multiple comparison test after Kruskal–Wallis test, significant difference [$p < 0.05$] between hydrothermal vents and the two other ecosystems). Moreover, publications on hydrothermal vents were cited significantly

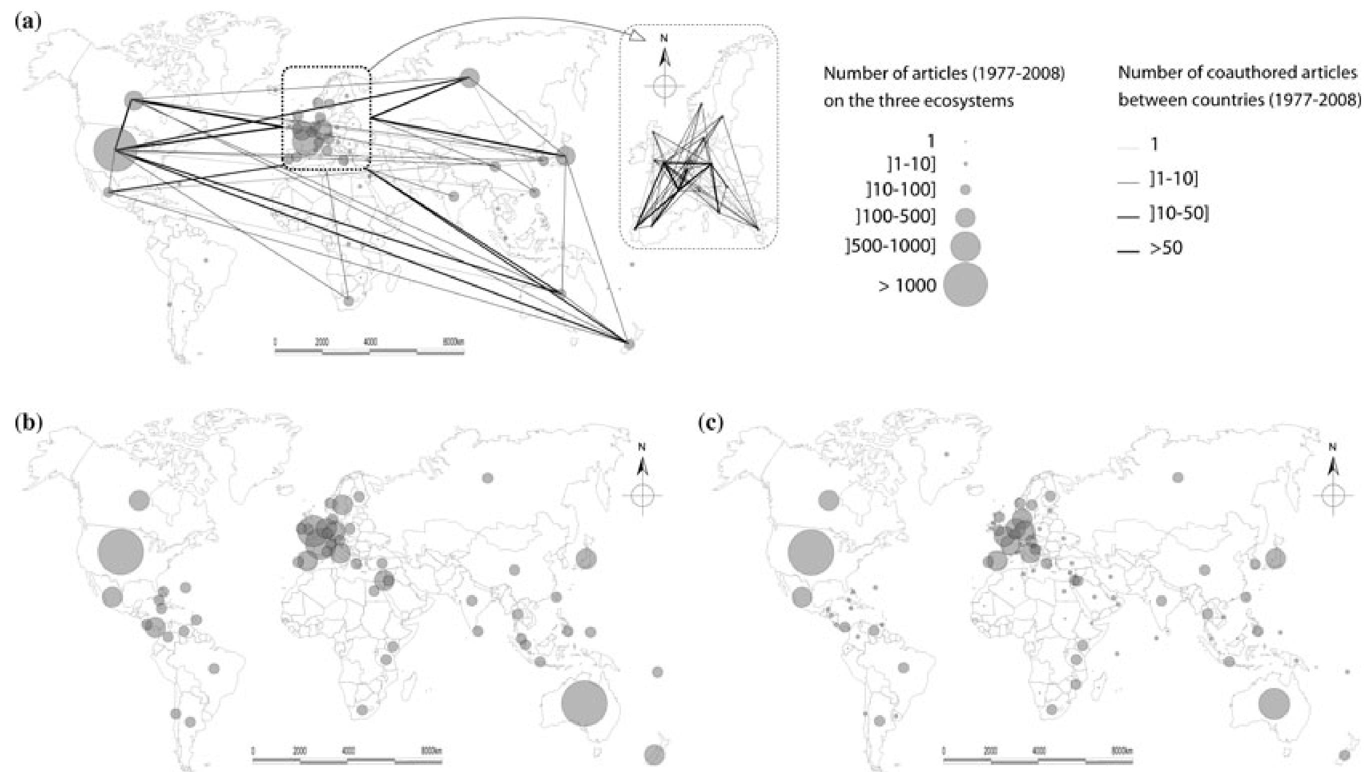

Figure 2. Number of articles on (a) hydrothermal vents, (b) coral reefs, and (c) seagrass beds published in the peer-reviewed literature from 1977–2008 (circles, number of published articles referenced in ISI Web of Science by author country affiliation), and number of articles with authors from multiple countries (lines, thickness corresponds to the number of coauthored articles between the different countries [the thicker the line the more articles]). For articles with coauthors from multiple countries, only countries with a minimum of 10 articles are presented, and collaborations within western Europe are shown separately (enclosed by dotted line).

more times per year (mean 2.4) than publications on coral reefs (2.3) and seagrass beds (1.9) (Kruskal–Wallis test, $p < 0.05$; multiple comparison test after Kruskal–Wallis test, significant difference [$p < 0.05$] between hydrothermal vents and the two other ecosystems).

The number of articles on hydrothermal vents, coral reefs, and seagrass beds published in the high impact-factor general-science journals *Nature* and *Science* differed significantly ($\chi^2 = 8.31$, df $= 2$, $p < 0.05$). Although similar numbers of articles were published in *Nature* and *Science* on hydrothermal vents ($n = 83$) and coral reefs ($n = 89$), the proportion of articles in these journals on hydrothermal vents (approximately 3% of the total number of publications) was 2.4 times greater than the proportion of publications on coral reefs (1.3%). Many fewer publications on seagrass beds were published in *Science* and *Nature* ($n = 6$, < 1% of the total number of publications). Most of the publications in *Nature* and *Science* on hydrothermal vents concern major discoveries such as adaptation of living organisms to extreme environments ($n = 31$ articles), geology and earth science ($n = 14$), chemistry ($n = 13$), and distribution of vent-associated biological communities ($n = 12$). Since the discovery of hydrothermal vents, publications describing new hydrothermal sites ($n = 6$) are still being published in *Nature* and *Science*.

Number of Scientific Cruises at Hydrothermal Vents

The known number of hydrothermal vent sites is 554, and they are concentrated spatially in a few regions (Fig. 3). The geological activity of 273 vent sites is unconfirmed; 229 vent sites are hydrothermally active and 52 are inactive (no evidence of fluid flow or communities of invertebrates that depend on vent fluid). The number of scientific cruises to vent sites has increased since 1976 (661 reported cruises 1976–2009) (Fig. 4). Over 50% of cruises were concentrated in three biogeographic provinces (as defined by Bachraty et al. 2009) northeastern Pacific (18.3% of the cruises), northern Mid-Atlantic Ridge (17.2%), and northeastern Pacific Rise (16.7%). Three other biogeographic provinces also have received

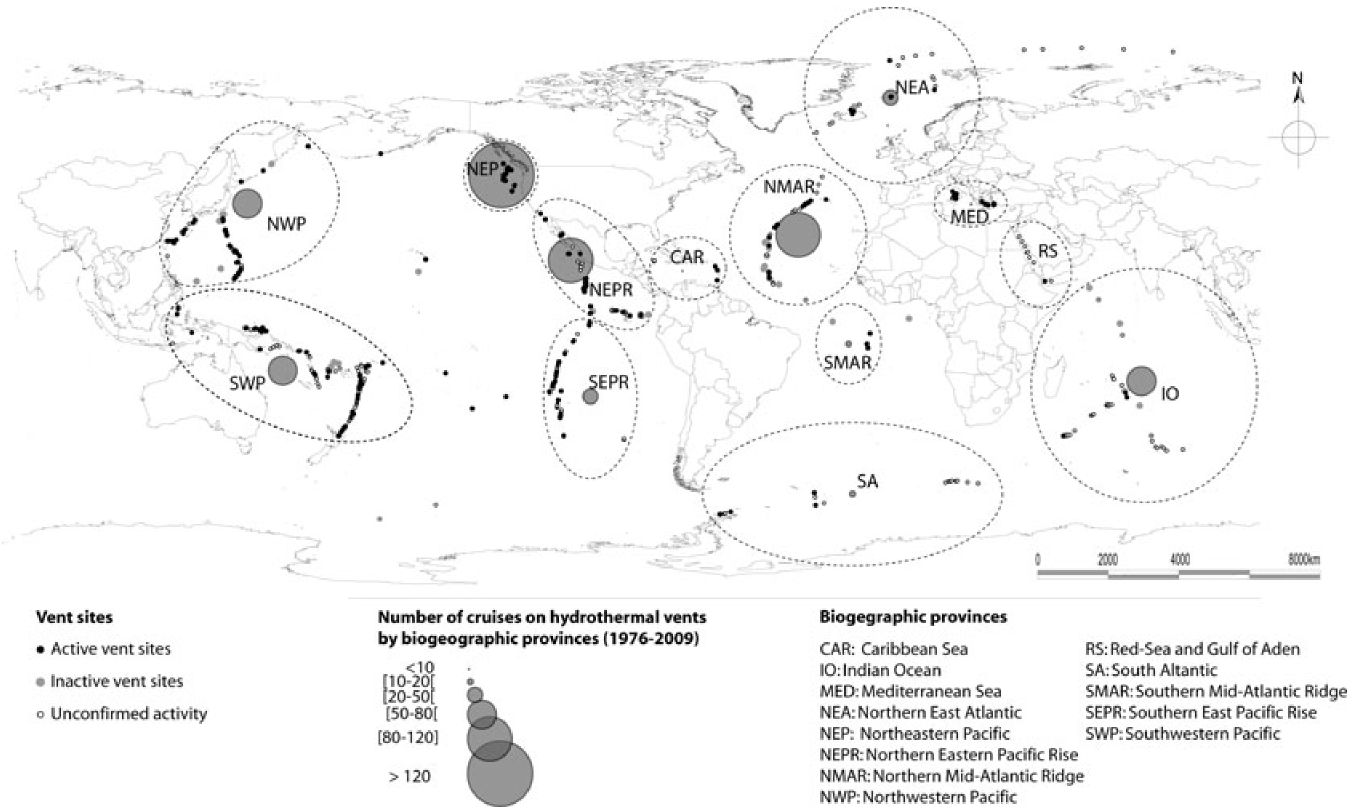

Figure 3. Number and distribution of the scientific cruises to hydrothermal vents from 1976 to 2009 reported in the InterRidge Cruise database (http://www.interridge.org/IRcruise). Biogeographic provinces (modified from Bachraty et al. [2009]) are outlined.

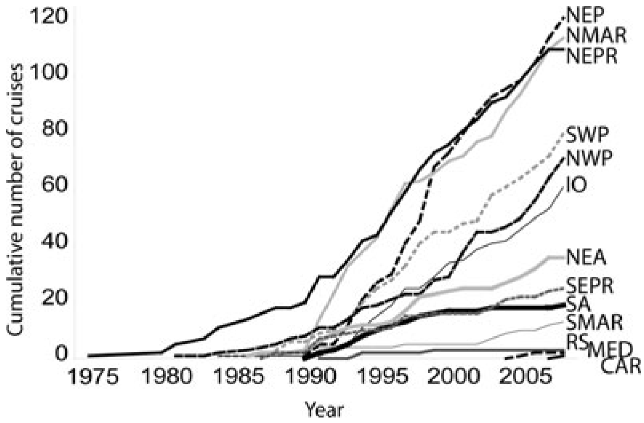

Figure 4. Number of scientific cruises to hydrothermal vents from 1976 to 2009 by biogeographic provinces reported in the InterRidge Cruise database (http://www.interridge.org/IRcruise) (CAR, Caribbean Sea; IO, Indian Ocean; MED, Mediterranean Sea; NEA, Northern East Atlantic; NEP, Northeastern Pacific; NEPR, Northern Eastern Pacific Rise; NMAR, Northern Mid-Atlantic Ridge; NWP, Northwestern Pacific; RS, Red-Sea and Gulf of Aden; SA, South Altantic; SMAR, Southern Mid-Atlantic Ridge; SEPR, Southern East Pacific Rise; SWP, Southwestern Pacific).

a relatively high proportion of visits: southwestern Pacific (12.0%), northwestern Pacific (10.6%), and Indian Ocean (9.2%). The northeastern Atlantic, southern east Pacific Rise, South Atlantic, and southern Mid-Atlantic Ridge were less visited (all provinces pooled, 14.0%); the Red, Mediterranean, and Caribbean seas remain little explored (1.1%).

Awareness and Perception of the ISRRP

Survey respondents included 164 individuals from 26 different countries (response rate approximately 5% assuming the survey reached 3000 people). The highest proportion of respondents were affiliated with institutions in the United States (39%), France (11%), United Kingdom (7%), and Germany (7%). Research scientists (47%) and professors (30%) composed the majority of respondents, followed by postdoctoral, PhD, and other graduate students (13%). Respondents were mostly from universities (54%) and governmental laboratories (24%). The mean age of respondents was 46 years. Respondents identified with 23 different disciplines, with many individuals reporting affiliation with more than one discipline. Most respondents were geochemists (30%), ecologists (29%), geologists (18%), geophysicists (12%), and microbiologists (10%). Respondents included individuals with relatively little experience in vent research (< 1 year experience, 15%; 0–15 days at sea, 21%) and individuals for whom hydrothermal vent research was their sole or major focus of research (>20 years experience, 20%; >200 days at sea, 22%).

Respondents mostly studied hydrothermal vents in the Atlantic Ocean (northern Mid-Atlantic Ridge, 35%; southern Mid-Atlantic Ridge, 10%), eastern Pacific Ocean (northern eastern Pacific Rise, 27%; northeastern Pacific, 23%), and the southwestern Pacific (33%). The majority of respondents (82%) were aware of the ISRRP. Among these individuals, 52% were informed of its existence via the InterRidge website or the InterRidge Newsletter.

Respondents indicated they considered the ISRRP necessary. For each question asking whether one of the six guidelines was necessary (i.e., Do you think this guideline is. . ..?), 1003 responses reported guidelines as *necessary*, 65 as *unsure*, and 38 as *unnecessary* (all guidelines pooled). The perceived necessity of individual guidelines differed among respondents ($\chi^2 = 22.88$, df = 12, $p = 0.029$): "*avoid collections that are not essential to the conduct of scientific research*. . ." and "*familiarize oneself with the status of current and planned research*. . ." garnered significantly more *unnecessary* and *unsure* responses. Moreover, responses differed significantly as a function of respondents' nationalities ($\chi^2 = 44.07$, df = 22, $p < 0.005$). All Japanese, Portuguese, and Spanish respondents thought all guidelines were necessary. American and New Zealand respondents had the most numerous *unsure* or *unnecessary* responses for the guidelines, although these responses constituted a small percentage (<27%) of overall responses for these nationalities.

Following the ISRRP seemed moderately feasible according to the respondents. For the question *Do you think that following this guideline is*. . .?, 586 responses reported following it as *easy*, 335 as *difficult*, 168 as *unsure*, and 14 as *not possible* (all guidelines pooled). There were significant differences among perceived feasibility of guidelines ($\chi^2 = 59.19$, df = 18, $p < 0.001$): "*familiarize yourself with the status of current and planned research*. . ." was the only guideline considered by a greater proportion of respondents (50%) as *difficult* rather than *easy* (34%) to follow. In contrast, "*avoid collections that are not essential to the conduct of scientific research*. . ." was considered the easiest to follow. Older respondents reported it is easier to follow the ISRRP than younger respondents (linear regression model, $p < 0.005$).

Although the majority of survey participants thought they followed the ISRRP, answers differed slightly among guidelines ($\chi^2 = 37.97$, df = 12, $p < 0.001$). For the question *Do you think you follow these guidelines?* 1051 respondents responded *yes*, 70 responded *unsure*, and 27 responded *no* (all guidelines pooled). "*Familiarize yourself with the status of current and planned research*. . ." gathered the largest proportion of *no* and *unsure* responses. The older the respondents, the more likely they were to claim they follow the ISRRP (linear regression model, $p < 0.001$), and response to this query also differed among nationalities ($\chi^2 = 50.38$, df = 33, $p < 0.05$). Respondents from New Zealand (29% *unsure*) and Japan (14% *unsure*) were less sure if they followed the guidelines, than respondents from Spain (100% *yes*), China (97% *yes*), and Portugal (96% *yes*).

Few respondents changed their behavior after reading the ISRRP. For the question *Did you change your behaviour after reading the code?* 850 respondents said *no*, 132 said *yes*, and 94 said *unsure* (all guidelines pooled). Survey participants were less confident in their colleagues' attitudes toward the ISRRP. Less than 50% of respondents answered *yes* to the question *Do you believe most organizations or researchers follow this guideline?* (522 responded *yes*, 361 responded *unsure*, and 225 responded *no*, all guidelines pooled). Furthermore, some guidelines were followed less than others ($\chi^2 = 102.13$, df = 12, $p < 0.001$): "*Avoid activities that will compromise experiments/observations of other researchers*..." was the only guideline for which more respondents answered *no* (66 responses) or *uncertain* (50 responses) than *yes* (42 responses). Responses to this guideline differed significantly according to participants' nationalities ($\chi^2 = 39.12$, df = 22, $p < 0.050$). The greatest number of *yes* responses regarding the behavior of other organizations or researchers came from Spanish respondents, whereas Russian, Mexican, and Canadian respondents answered *no* most frequently. Respondents aware of the ISRRP were more likely to believe that most organizations or researchers follow the guidelines ($\chi^2 = 23.21$, df = 2, $p < 0.001$).

Discussion

Importance of Hydrothermal Vents for Science and Scientists

Hydrothermal vents have neither high concentrations of species richness nor are they threatened by human activities to the same degree as many terrestrial or marine ecosystems. Vent ecosystems, however, have relatively high proportions of endemic species (Tunnicliffe et al. 1996), and mining of these areas is likely to become more common by 2020 (Hoagland et al. 2010). Moreover, most citizens are unaware of deep-sea hydrothermal-vent ecosystems and few would consider vent organisms charismatic or part of their everyday concern and interest. Nevertheless, hydrothermal vents have high value as study systems for the scientific community. Our analysis revealed that despite the discovery of hydrothermal vents 30 years ago and that there are likely a large number of undiscovered vents (German et al. 2008), the quantity of knowledge gathered to date from hydrothermal systems approaches what has been discovered in seagrass beds and coral reefs during the same interval. The effect of scientific discoveries at hydrothermal vents is higher than what we found for the two other ecosystems (in terms of impact factor and citations in the scientific literature). Nevertheless, this result can be biased by differences in subject areas studied in the three ecosystems and multidisciplinary (and multinational) efforts are particularly characteristic of research on hydrothermal vents.

The knowledge value of natural systems is seldom reported in peer-reviewed journals. By trying to maintain objectivity, scientists likely exclude themselves as stakeholders. But scientists have a direct interest in conserving natural systems. Moreover, we believe scientists have an important responsibility for conservation of vent ecosystems because they are one of the few groups that visit these ecosystems regularly, and they have the potential to harm these systems through activities such as observation, sampling, and instrument deployment.

Effect of Scientific Activity on Vent Ecosystems

The history of scientific expeditions to hydrothermal vents (Fig. 3) indicates that activity is concentrated at a relatively small number of vent fields (Dando & Juniper 2001). In the span of 34 years, nearly 700 cruises visited dozens of hydrothermal-vent fields, of which more than 300 were located at a few places in the northeastern Pacific, the northeastern Pacific Rise, and the northern Mid-Atlantic Ridge. Research pressure on a given vent system resulting from field campaigns may thus be focused and extensive.

The types of direct effects on vent ecosystems by scientific research are diverse. For example, removal of bathymodiolin mussels (*Bathymodiolus* spp.) from mussel beds alters fluid chemistry and fluid dispersion patterns (Johnson et al. 1994). Tubeworm clusters and other sessile organisms may be especially vulnerable to disturbances from submersible activity that destroys their habitat or alters fluid flow patterns (e.g., Tunnicliffe 1990). The magnitude of effects of these and similar activities on hydrothermal-vent animals typically is equal to natural disturbances. Natural disturbances, such as volcanic activity, may cause local extinction over large areas (many square kilometers). Indirect effects that may result from scientific research include transfer of species or pathogens through ballast waters of submersibles. Discovery of fungal infections in bathymodiolin mussel populations in Fiji Basin raised the theoretical possibility of infecting other populations through contaminated sampling equipment and submersibles (Van Dover et al. 2007).

Tools scientists use to study hydrothermal vents differ by discipline and type of study. Dredges, trawls, and rock sleds are useful tools for exploratory work, but they scrape the substratum and increase sedimentation, destroy the habitat of some animals (Jones 1992), and remove species sensitive to disturbance (Thrush & Dayton 2002). Discriminating sampling tools are used with submersibles (e.g., suction samplers, nets, scoops, water samplers) and are used for fine-resolution studies of the environment or a particular species or its habitat. Although effects from precision sampling tools are small in extent and targeted, there can be indirect or accidental effects from this type of sampling. For example, high-energy floodlights on submersible vessels have been implicated in retinal damage of vent shrimp (Herring et al. 1999). Submersible thrusters may damage communities and stir up sediment near where they are used (Tunnicliffe 1990), and hydrothermal chimney structures can be particularly friable and easily toppled with certain sampling gear. One of the least invasive sampling tools at hydrothermal vents is video imagery, which is used to map faunal distributions, estimate biomass, and observe behavior (Chevaldonné & Jollivet 1993). Studies in which video imagery is used are now placed in a geospatial framework for study of community ecology and temporal dynamics (e.g., Podowski et al. 2009). Although video studies are minimally invasive, they often require ground-truthing with collection of physical samples.

Toward Sustainable Use of Hydrothermal Vents by Scientists

The idea of a voluntary code of conduct for scientists who conduct research on hydrothermal vents was proposed in the late 1990s (e.g., Mullineaux et al. 1998; Glowka 2003), but the ISRRP was the first proposition reached by consensus among an international community of scientists. It presents clear guidelines for scientific research in vent ecosystems. Our study represents the first assessment of community awareness and perceptions of this code. Overall, we found deep-sea scientists are familiar with ISRRP, although scientists familiar with the ISRRP may have been more likely to participate in the survey than scientists unfamiliar with it. Respondents thought it would be difficult to be familiar with research in an area and to avoid activities that would compromise on-going studies. To facilitate adherence to this guideline, InterRidge lists locations of field campaigns and ongoing, site-specific experiments and observations (http://www.interridge.org/IRcruise), but listings are voluntary, brief, and not up to date.

Respondents thought the ISRRP was useful, and most (90%) believed they abided by the code, although 50% doubted their colleagues followed the code. Overall we found that respondents believed they followed the code, but were unsure whether others follow the code and would like more information on how others follow the code. It is difficult to measure the extent to which scientists comply with the ISRRP, and, in the end, sustainable use of hydrothermal vents by scientists relies on voluntary behavior and respect for the ideals behind ISRRP. The ISRRP is a useful reminder for scientists, but is probably not sufficient to ensure sustainable scientific activity.

We believe, as suggested by Mullineaux et al. (1998), Devey et al. (2007), and Glowka (2003), that scientific activities should be managed for conservation for the same reasons mining, harvesting, or tourism are managed. Conservation areas have been established in certain national waters (Allsopp et al. 2009). The Endeavour Marine Protected Area (Juan de Fuca Ridge; Canada), the Lucky Strike and Menez Gwen Protected Area (Mid-Atlantic Ridge; Portugal), and the Guaymas Basin and Eastern Pacific Rise Hydrothermal Vents Sanctuary (Mexico) are deep-sea vent fields managed for multiple scientific uses. The Marianas Trench Marine National Monument (western Pacific, U.S.A.) includes a submarine volcanic unit that is protected for its scientific importance. A general approach toward managed networks of chemosynthetic ecosystems proposed by scientists and experts in ocean governance and ocean industry (http://www.ventseepconservation.org) could serve as a convenient framework within which to manage scientific activities in a sustainable manner.

Scientists are often involved in evaluation of status of world natural heritage sites and, together with other stakeholders, can evaluate the status of hydrothermal vents. Because scientists benefit from these living libraries and have the potential to degrade them, they are stakeholders and we believe they have a special responsibility for exemplary behavior.

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Supporting Information

The survey form sent to scientists working on hydrothermal vents (Appendix S1) is available as part of the online article (Appendix S1). The authors are responsible for the content and functionality of these materials. Queries (other than absence of the material) should be directed to the corresponding author.

Literature Cited

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