THEMATIC ANNOTATED LITERATURE REVIEW:

Socioeconomic and Decision Value of HAB Forecasting and Satellite Monitoring

Sea Grant

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Contents

Thematic Annotated Literature Review: Socioeconomic and Decision Value of HAB Forecasting and Satellite Monitoring

Introduction

This thematic annotated literature review synthesizes research on the socioeconomic and decision value of harmful algal bloom (HAB) forecasting and satellite monitoring. It focuses on how information, especially forecasts and satellite data, reduces uncertainty, informs decisions, and produces societal benefits.

Scope, Selection, and Purpose: The review summarizes what is currently known about the economic and practical value of HAB forecasts and satellite information, with emphasis on how improved information supports better decisions across public health, fisheries and aquaculture, recreation, and water resource management. Priority is given to studies that evaluate the value of information from forecasts, satellite observations, and decision support systems, including formal economic valuation, Value of Information (VoI), and decision analytic approaches. Studies focused primarily on HAB damages are included where they inform valuation, management choices, or the benefits of enhanced monitoring and early warning. The review draws on targeted searches of peer reviewed publications, government reports, and technical literature related to HAB forecasting, satellite monitoring, and decision support. Each annotation includes concise fields (e.g., purpose, audience, application, monetized value) to facilitate comparison across studies.

Organization: The review is organized into four major themes: (1) economic and management value of HAB forecasts, (2) the role of satellite observations in detection and operational decisions, (3) decision analytic and Value of Information approaches, and (4) broader frameworks for valuing environmental and satellite based information.

Interconnections: Many sources span multiple themes; for example, work monetizing the value of satellite enabled HAB alerts contributes to both socioeconomic assessment (Theme 1) and operational remote sensing value (Theme 2). These overlaps highlight how information quality, institutional uptake, and valuation methods jointly shape outcomes.

Together, these elements provide a foundation for understanding the value of HAB forecasts and satellite information and how they inform management and planning decisions.

THEME 1

Socioeconomic Value of HAB Forecasts and Decision Support

The papers in Theme 1 are organized to move from broad economic valuation frameworks to region-specific and application-focused studies. The sequence begins with conceptual or methodological analyses that establish approaches for estimating socioeconomic costs and damages of HABs. It then proceeds to studies that apply these methods to specific regions or populations, highlighting both direct and indirect economic consequences. Within each cluster, papers are arranged chronologically to illustrate the development of valuation methods and the growing emphasis on linking HAB forecasts and early warning to tangible management and societal outcomes. Recent Florida studies estimating tourism losses of ~$2.7 B (Alverez et al., 2024[1]) during the 2017–2019 red tide and ~$184 M (Ferreira et al., 2022[2]) in the accommodations market for 2018 alone, underscore the scale of damages that forecast-based advisories seek to mitigate by enabling risk-aware behavior, adjusted harvest timing, targeted warnings, and reduced exposure.

[1] Alvarez, Sergio & Brown, Christina & Diaz, Marc & O'Leary, Heather & Solis, Daniel. (2024). Non-linear impacts of harmful algae blooms on the coastal tourism economy. Journal of Environmental Management. 351. 119811. 10.1016/j.jenvman.2023.119811. https://doi.org/10.1016/j.jenvman.2023.119811

[2] Ferreira, J.P., Bijen Saha, B., Carrero, G. C., Kim, J., & Court, C. (2023). Impacts of red tide in peer-to-peer accommodations: A multi-regional input-output model. *Tourism Economics*, 29(3), 812-834. https://doi.org/10.1177/13548166211068276

Hoagland, P., Anderson, D. M., Kaoru, Y., & White, A. W. (2002). *The economic effects of harmful algal blooms in the United States: Estimates, assessment issues, and information needs.* Estuaries, 25(4), 819–837. https://doi.org/10.1007/BF02804908 *Publication type: Peer-reviewed journal article*

■ **Purpose:** Synthesize available evidence on the economic impacts of HABs in the United States and identify information gaps relevant to management and policy responses.

■ **Audience:** Environmental economists, marine scientists, policymakers, and coastal resource managers concerned with HAB impacts and mitigation strategies.

■ **Geographic Range:** United States coastal and estuarine systems.

■ **Summary:** This foundational paper synthesizes available estimates of economic damages caused by HABs in the United States, including impacts on fisheries, aquaculture, tourism, and public health. The authors estimate national annual damages on the order of tens of millions of dollars (with substantial uncertainty) and emphasize that these figures likely underestimate true costs. Importantly, the paper highlights deficiencies in monitoring and forecasting information as a key barrier to effective management and improved economic outcomes.

■ **Application:** Supports prioritization of monitoring, forecasting, and response strategies at regional and national levels. Provides an evidence base for policy interventions, including investment in predictive models, satellite-based monitoring, and public advisories. The study also guides future research on integrating economic valuation with ecological monitoring.

■ **Conclusion:** National HAB damages are substantial and underscore the need for improved valuation methods, expanded monitoring, and proactive management. Results support economic justification for investment in information systems and mitigation programs.

■ **Monetized Value:** Yes, national-scale economic damages across fisheries, aquaculture, tourism, and public health; magnitude on the order of tens of millions of dollars annually (United States; year not standardized across sources).

Moeltner, K., Fanara, T., Foroutan, H., Hanlon, R., Lovko, V., Ross, S., & Schmale III, D. (2023). *Harmful algal blooms and toxic air: the economic value of improved forecasts.* Marine Resource Economics, 38, 1–28. https://doi.org/10.1086/722598 *Publication type: Peer-reviewed journal article*

■ **Purpose:** Estimate the economic benefits of improved HAB-related air quality forecasts using stated preference and choice experiment methods.

■ **Audience:** Oceanographers, environmental economists, and scientists involved in HAB forecasting, human health impacts, and decision-support tools.

■ **Geographic Range:** Southwest Florida (Florida red tide region).

■ **Summary:** This study surveyed households to estimate their Willingness to Pay (WTP) for 24-hour forecasts of airborne red tide toxins. Survey responses indicate that individuals value accurate forecasts for health protection, recreational planning, and reducing exposure. Per-household WTP ranged from

$17–$45 per year, and when aggregated across affected populations in Southwest Florida, the total societal benefit is estimated at approximately $14.5 million annually. The paper highlights how even incremental improvements in forecast accuracy can reduce health risks, lost recreational opportunities, and associated economic costs.

■ **Application:** Provides actionable information for policymakers and HAB managers on the economic justification for investing in enhanced airborne HAB forecasting systems. The findings can inform cost-benefit analyses for satellite- and ground-based monitoring, forecast development, and public communication strategies. The methods are transferable to other regions where HAB toxins impact public health and recreation.

■ **Conclusion:** Even modest improvements in toxin forecasts can substantially reduce health impacts and economic losses. WTP-based valuation provides an actionable framework for policy and management.

■ **Monetized Value:** Yes, household WTP for 24-hour airborne toxin forecasts, $17–$45 per household per year; aggregated to ~$14.5 million annually (Southwest Florida; stated preference).

Carias, J. C., Vásquez-Lavín, F., Barrientos, M., Ponce Oliva, R. D., & Gelcich, S. (2024). *Economic valuation of Harmful Algal Blooms (HAB): Methodological challenges, policy implications, and an empirical application.* Journal of Environmental Management. https://doi.org/10.1016/j.jenvman.2024.121566 *Publication type: Peer-reviewed journal article*

■ **Purpose:** Review and synthesize economic valuation methods for HAB damages, linking valuation to policy and management decisions.

■ **Audience:** Environmental economists, resource managers, policymakers, and scientists interested in HAB damages and decision-support.

■ **Geographic Range:** Empirical application centered on Chilean coastal systems, with conceptual and methodological insights applicable to marine and freshwater HAB-affected regions globally.

■ **Summary:** This paper examines why HAB economic damages are often underestimated, especially when only direct market losses are considered. Using an integrated valuation framework applied to Chilean coastal systems, the authors monetize indirect and non-market damages such as ecosystem service losses, fisheries disruption, and public health risks. The study provides monetized estimates of HAB damages at a regional scale, demonstrating substantial societal costs.

■ **Application:** The framework informs HAB policy, compensation mechanisms, and management strategies by combining multiple economic methods. It supports decisions on monitoring, early warnings, mitigation investments, and response planning, particularly for aquaculture and fisheries sectors.

■ **Conclusion:** Integrated economic valuation is essential to capture the full societal costs of HABs. Linking economic analysis with HAB monitoring and management supports proactive, cost-effective interventions.

■ **Monetized Value:** Yes, regional HAB damages including fisheries, ecosystem services, and public health; (Chile; USD, aggregated regionally).

Jin, D., Kourantidou, M., Weir, M. J., & Horstmann, I. (2024). *Assessing the value of harmful algal bloom forecasts in the Pacific Northwest.* ICES Journal of Marine Science, 81(9), 1796–1816. https://doi.org/10.1093/icesjms/fsae126 *Publication type: Peer-reviewed journal article*

■ **Purpose:** Assess the management benefits of HAB forecasts in supporting marine resource management and decision-making.

■ **Audience:** Scientists, economists, and resource managers working in marine science, HAB forecasting, and environmental decision support.

■ **Geographic Range:** Pacific Northwest coastal waters (United States).

■ **Summary:** This study models the management benefits of HAB forecasts by comparing outcomes with and without forecast information (e.g., adjusted harvest schedules, advisories, reduced exposure). The authors simulate scenarios both with and without forecasts, highlighting how timely information can prevent overharvesting, reduce contamination risks in shellfish, and minimize lost revenue from temporary closures. While the study does not report explicit dollar values, it demonstrates the relative reduction in economic losses and risks across multiple fisheries sectors.

■ **Application:** Provides a framework for integrating forecast information into operational management decisions. Supports proactive scheduling of shellfish harvests, resource allocation for monitoring, and the timing of closures or advisories. Offers a transferable methodology for assessing forecast benefits in other regions and for different types of harmful blooms.

■ **Conclusion:** HAB forecasts enhance decision-making efficiency, reduce uncertainty, and improve operational outcomes for the seafood industry and public health protection. Investment in forecasting infrastructure is supported even without direct monetization.

■ **Monetized Value:** No explicit dollar values, modeled reductions in closures and harvest losses imply avoided costs but are not monetized.

NANOOS/WHOI/NOAA (2024). *Value of the Pacific Northwest HAB Forecast (PNW HAB Bulletin).* https://coastalscience.noaa.gov/project/value-of-the-pacific-northwest-hab-forecast/ ; Valuation summary: https://www2.nanoos.org/products/habs/forecasts/valuation.php ; Example bulletin: https://bpb-us-e1.wpmucdn.com/sites.uw.edu/dist/a/28304/files/2025/02/pnw_hab_bulletin-20240816.pdf *Publication type: Federal project page; program valuation summary; operational bulletin artifact*

■ **Purpose:** Document and evaluate the value of information (VoI) produced by the PNW HAB Bulletin's forecasts to guide shellfish and crab management decisions.

■ **Audience:** State/tribal shellfish managers, fisheries economists, observing system sponsors.

■ **Geographic Range:** Washington and Oregon coasts.

■ **Summary:** Valuation results indicate that forecast information enables selective openings, targeted sampling, and earlier advisories, which improve both economic outcomes and public health protection for coastal communities. Under observed bloom frequencies and plausible forecast skill, the benefits exceed program costs, providing a direct economic justification for operational continuity. Project materials also trace the transition from research to operational dissemination, with concrete use cases and routine decision touchpoints. Live bulletin examples illustrate how spatially explicit risk cues are delivered at beach and offshore hotspot scales to inform weekly management.

■ **Application:** Offers a transferable template for integrating forecast products into shellfish risk management and for structuring benefit–cost arguments for forecast operations.

■ **Conclusion:** Continued funding of the PNW Bulletin is economically justified and manager-relevant under current and projected HAB risk regimes.

■ **Monetized Value:** Partially, VoI/benefit–cost criteria indicate benefits outweigh costs; estimates are conservative due to excluded spillovers.

Stroming, S., Robertson, M., Mabee, B., Kuwayama, Y., & Schaeffer, B. (2020). *Quantifying the human health benefits of using satellite information to detect cyanobacterial harmful algal blooms and manage recreational advisories in U.S. lakes.* GeoHealth, 4, e2020GH000254. https://doi.org/10.1029/2020GH000254
Publication type: Peer-reviewed journal article

■ **Purpose:** Calculate the socioeconomic benefits, particularly human health benefits, of using satellite remote sensing to detect cyanobacterial harmful algal blooms (cyanoHABs) and inform recreational advisories.

■ **Audience:** Scientists, environmental economists, water resource managers, and public health researchers interested in remote sensing, HABs, and environmental benefit assessment.

■ **Geographic Range:** U.S. lakes, with a detailed case study at Utah Lake.

■ **Summary:** Using satellite remote sensing to detect cyanoHABs, the authors calculate human health benefits from timely recreational advisories. Approximately 8,000 people would have been exposed in the 2017 Utah Lake bloom without satellite data, resulting in avoided health costs of $370,000 (2017 USD) (sensitivity range $55,000–$1,057,000).

■ **Application:** Combines satellite, public health, and economic data to calculate avoided costs. Supports integration of satellite information into public health advisories and decision-making for HAB management.

■ **Conclusion:** Satellite HAB detection provides clear socioeconomic benefits by reducing exposure, illness, and associated costs. The framework is transferable to other freshwater systems.

■ **Monetized Value:** Yes, avoided recreational illness costs, Utah Lake, ~$370,000 (2017 USD); sensitivity $55,000–$1,057,000; cost-of-illness calculation.

THEME 2

HAB Management Value of Satellite Observations and Remote Sensing

The papers in Theme 2 are organized to move from broader institutional and policy context to evidence of user uptake, followed by technical and operational studies, and finally research assessing socioeconomic value. It begins with analyses that establish the framework within which satellite monitoring and HAB management operate. Next are surveys and case studies that document how downstream managers and stakeholders apply satellite and forecast information in decision-making. This is followed by studies demonstrating satellite-based detection methods and operational integration in freshwater and coastal systems. The sequence concludes with research assessing the economic and social benefits of satellite-enabled HAB forecasting and early warning. Within each cluster, papers are arranged chronologically to illustrate the evolution of methods, understanding, and application over time.

U.S. Government Accountability Office (2022). *Water Quality: Agencies Should Take More Actions to Manage Risks from Harmful Algal Blooms and Hypoxia.* GAO-22-104449. Published June 15, 2022. https://www.gao.gov/products/gao-22-104449 *Publication type: Government Report*

■ **Purpose:** Evaluate federal efforts to manage HAB and hypoxia risks, focusing on interagency coordination, monitoring, forecasting, and support for state and local response. Although not satellite-specific, the report evaluates the institutional context within which satellite-enabled monitoring systems operate.

■ **Audience:** Policymakers, federal agencies, and oversight bodies

■ **Geographic Range:** United States (national federal program review).

■ **Summary:** The GAO assessed federal implementation of the Harmful Algal Bloom and Hypoxia Research and Control Act, examining NOAA and EPA coordination, research plans, and monitoring programs. Findings indicate a lack of a unified national program and gaps in monitoring, particularly for freshwater systems. While satellite monitoring and forecasting are mentioned, the report emphasizes institutional barriers, resource limitations, and the need for clear performance metrics. The report also documents the potential economic and health benefits of improved monitoring and early warning systems, noting that timely information could reduce exposure, minimize damages, and support management decisions.

■ **Application:** Provides critical policy and operational context for federal HAB management, including the status and gaps in monitoring and forecasting activities that rely on satellite and in situ data. Supports development of coordinated monitoring frameworks, prioritization of resources, and guidance for federal, state, and tribal agencies on improving early warning systems.

■ **Conclusion:** Strengthening coordination and performance metrics is essential for realizing the full value of HAB monitoring and forecasting investments.

■ **Monetized Value:** No, policy and program evaluation; economic benefits implied but not quantified.

Staugler, E. A. (2025). *Usefulness of NOAA NCCOS Satellite Imagery Emails for HAB Monitoring in the Northeast U.S.* Florida Sea Grant. https://www.flseagrant.org/publication/usefulness-of-noaa-nccos-satellite-imagery-emails-for-harmful-algal-blooms-in-the-northeast-u-s/ *Publication type: Technical report (survey)*

■ **Purpose:** Evaluate user satisfaction, preferences, and operational use of NOAA's satellite HAB imagery distributed to stakeholders in the Northeastern United States.

■ **Audience:** State, local, and federal agency staff, academic partners, non-governmental organizations, and water quality managers using satellite HAB imagery for operational decisions.

■ **Geographic Range:** Northeastern U.S. coastal waters (Maine to New Jersey).

■ **Summary:** This report presents a survey of recipients of NOAA NCCOS HAB satellite imagery emails, documenting how users engage with the emails, their satisfaction with content and presentation, and how the emails inform monitoring and decision-making. Respondents reported that the emails are generally useful for situational awareness, planning monitoring activities, and coordinating with other agencies. The report also includes qualitative feedback and recommendations to improve formatting and clarity of imagery interpretation.

■ **Application:** Provides qualitative evidence of actual user engagement with satellite imagery, informing product development, communication strategies, and operational HAB monitoring.

■ **Conclusion:** Satellite HAB imagery is valued and used operationally by practitioners in the Northeast, reinforcing the relevance of satellite observations for HAB management beyond technical performance metrics.

■ **Monetized Value:** No, qualitative user engagement; no economic valuation.

Agnoli, L., Urquhart, E., Georgantzis, N., Schaeffer, B., Simmons, R., Hoque, B., Neely, M. B., Neil, C., Oliver, J., & Tyler, A. (2023). *Perspectives on user engagement of satellite Earth observation for water quality management.* Technological Forecasting & Social Change, 189, 122357. https://doi.org/10.1016/j.techfore.2023.122357 *Publication type: Peer-reviewed journal article*

■ **Purpose:** Examine how user engagement, institutional context, and communication influence the uptake and effective use of satellite Earth observation data for water quality management.

■ **Audience:** Scientists, remote sensing practitioners, policymakers, water quality managers, and agencies involved in environmental monitoring and decision-support.

■ **Geographic Range:** Multi-regional, including the United States and Europe, with case studies spanning coastal and inland water management contexts.

■ **Summary:** This study investigates how satellite Earth observation data are integrated into water quality management through interviews, surveys, and case analyses of operational users. Rather than focusing on technical performance or economic valuation, the paper highlights social and institutional factors—such as trust, co-production, data usability, and organizational capacity—that determine whether satellite data generate actionable value. The findings show that misalignment between data products and management needs can limit benefits, even when high-quality satellite information is available.

■ **Application:** Supports the design of satellite-based water quality monitoring systems that prioritize user engagement, co-developed products, and sustained interaction between data providers and decision-makers, thereby increasing the likelihood that satellite information informs management actions such as advisories and monitoring prioritization.

■ **Conclusion:** The realized value of satellite Earth observation for water quality management depends on effective user engagement and institutional integration, not

solely on technological capability. Addressing social and organizational barriers is essential for translating satellite data into meaningful management outcomes.

■ **Monetized Value:** No, qualitative assessment of value realization; no economic valuation.

Stumpf, R. P., Tomlinson, M. C., Calkins, J. A., Kirkpatrick, G. J., Fisher, K., Nierenberg, K., Currier, R., & Wynne, T. (2009). *Skill assessment for an operational algal bloom forecast system.* Journal of Marine Systems, 76(1–2), 151–161. https://doi.org/10.1016/j.jmarsys.2008.05.016 *Publication type: Peer-reviewed journal article*

■ **Purpose:** Evaluate the performance and reliability of an operational satellite-based algal bloom forecast system used to support coastal management decisions.

■ **Audience:** Oceanographers, remote sensing scientists, HAB forecasters, and coastal resource managers involved in operational monitoring and forecasting systems.

■ **Geographic Range:** Gulf of Mexico (Florida red tide region), with relevance to other coastal HAB forecast systems.

■ **Summary:** This paper assesses the forecast skill of NOAA's operational harmful algal bloom (HAB) forecast system, which integrates satellite ocean color observations with expert analysis. The authors evaluate forecast accuracy, false positives, and missed events, demonstrating that satellite-based forecasts provide meaningful early warning capability compared to reliance on in situ sampling alone. While the study does not monetize benefits, it establishes that forecast information is sufficiently reliable to support management actions such as shellfish closures and public advisories.

■ **Application:** Provides empirical evidence that satellite-enabled HAB forecasts meet operational performance thresholds required for management use. The results underpin later economic valuation studies by demonstrating that forecast information is credible and actionable.

■ **Conclusion:** Operational satellite-based HAB forecast systems provide demonstrable management value by improving early detection and situational awareness, forming a critical foundation for decision-support and valuation analyses.

■ **Monetized Value:** No, technical performance only; economic value implied but not quantified.

Papenfus, M., Schaeffer, B., Pollard, A. I., & Loftin, K. (2020). *Exploring the potential value of satellite remote sensing to monitor chlorophyll-a for US lakes and reservoirs.* Environmental Monitoring and Assessment, 192, 808. https://doi.org/10.1007/s10661-020-08631-5 *Publication type: Peer-reviewed journal article*

■ **Purpose:** Assess the potential value of satellite remote sensing for monitoring chlorophyll-a concentrations across U.S. lakes and reservoirs.

■ **Audience:** Scientists, environmental managers, and remote sensing specialists focused on inland water quality monitoring.

■ **Geographic Range:** United States lakes and reservoirs.

■ **Summary:** This study assesses how satellite-derived chlorophyll-a data can fill spatial and temporal gaps in traditional in situ monitoring programs. While no explicit economic values are reported, the authors demonstrate that satellite monitoring provides earlier detection of bloom events, improved spatial coverage, and supplemental data to guide management actions. The paper highlights the importance of resolution, algorithm accuracy, and integration with field sampling to maximize the utility of satellite observations for operational water quality management.

■ **Application:** Provides a framework for integrating satellite data into water quality assessment workflows, highlighting the role of satellite coverage, resolution, and algorithm performance in decision-making. The study emphasizes how improved information quality enhances decision-making, even in the absence of direct monetized benefits.

■ **Conclusion:** Satellite remote sensing is a valuable complement to traditional monitoring, enhancing HAB detection and supporting informed management decisions across U.S. freshwater systems. The potential operational benefits highlight the importance of investment in remote sensing capabilities, integration with in situ data, and development of user-friendly information products.

■ **Monetized Value:** No, economic value implied through improved detection and management efficiency, but not explicitly quantified.

Lopez Barreto, B. N., Hestir, E. L., Lee, C. M., & Beutel, M. W. (2024). *Satellite remote sensing: A tool to support harmful algal bloom monitoring and recreational health advisories in a California reservoir.* GeoHealth, 8, e2023GH000941. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC10885757/ *Publication type: Peer-reviewed journal article*

■ **Purpose:** Demonstrate how satellite remote sensing supports detection of HABs and informs recreational health advisories.

■ **Audience:** Environmental scientists, water resource managers, public health officials, and remote sensing specialists.

■ **Geographic Range:** California, United States.

■ **Summary:** This study demonstrates how satellite remote sensing improves detection and spatial characterization of cyanobacterial HABs in a California reservoir compared to in situ sampling alone. Satellite-based monitoring enables earlier and more comprehensive identification of bloom events, supporting timely public health advisories. Economic benefits are implied through reduced monitoring effort and avoided public health exposure.

■ **Application:** Satellite-based HAB monitoring supports timely recreational health advisories by improving situational awareness and reducing reliance on limited field sampling. The approach demonstrates clear socioeconomic value by enabling earlier warnings, reducing human exposure risk, and supporting more efficient allocation of monitoring resources for water managers.

■ **Conclusion:** Satellite remote sensing enhances HAB monitoring and management decision-making, providing clear value for public health and operational efficiency.

■ **Monetized Value:** No, economic value implied, not quantified.

Schaeffer, B. A., Reynolds, N., Ferriby, H., Salls, W., Smith, D., Johnston, J. M., & Myer, M. (2024). *Forecasting freshwater cyanobacterial harmful algal blooms for Sentinel-3 satellite resolved U.S. lakes and reservoirs.* Journal of Environmental Management, 349, 119518. https://doi.org/10.1016/j.jenvman.2023.119518 *Publication type: Peer-reviewed journal article*

■ **Purpose:** Develop and evaluate a predictive forecasting model for cyanobacterial harmful algal blooms (cyanoHABs) across satellite-resolvable lakes in the contiguous United States using weekly Sentinel-3 satellite data.

■ **Audience:** Water resource managers, public health officials, remote sensing specialists, and environmental scientists interested in operational HAB forecasting and early warning systems.

■ **Geographic Range:** United States (continental U.S. freshwater lakes and reservoirs detectable via Sentinel-3).

■ **Summary:** This study constructs a hierarchical Bayesian spatiotemporal model driven by weekly satellite-derived cyanobacteria abundance (via the Ocean and Land Colour Instrument on Sentinel-3) to forecast exceedance of WHO Alert Level 1 chlorophyll-a thresholds across 2,192 U.S. lakes. The model achieved ~90 % overall accuracy (88 % sensitivity, 91 % specificity) in predicting weekly bloom occurrence, outperforming several machine-learning and neural network approaches. Forecast results provide probabilistic guidance on cyanoHAB risk for water managers, enabling improved planning and prioritization of monitoring and advisories.

■ **Application:** By linking satellite observations with predictive modeling, the paper demonstrates how operational forecasts can enhance situational awareness for public health and water quality decision-making, helping managers allocate sampling resources and issue timely advisories based on predicted bloom risk.

■ **Conclusion:** Satellites can be used not just for passive detection of blooms but to drive near-real-time forecasting tools that improve early warning and operational decision making for HAB risks.

■ **Monetized Value:** No, economic value not directly quantified; operational value implied through improved forecasting and risk reduction potential.

U.S. Environmental Protection Agency (2024). *Experimental cyanobacterial harmful algal bloom forecasting model using satellite data.* U.S. EPA Water Research. https://www.epa.gov/water-research/cyanobacterial-harmful-algal-blooms-forecasting-research *Publication type: Government Website*

■ **Purpose:** Describe the development and application of an experimental freshwater

harmful algal bloom (cyanoHAB) forecasting model that uses satellite-derived data from the Cyanobacteria Assessment Network (CyAN) to predict weekly probabilities of bloom occurrence.

■ **Audience:** State and local water quality managers, public health officials, and drinking water utilities.

■ **Geographic Range:** Contiguous United States (2,192 satellite-resolvable lakes and reservoirs).

■ **Summary:** The CyAN forecasting model integrates satellite observations with statistical models to generate early warnings of cyanobacterial bloom risk. While the site does not present economic valuation, it illustrates how near-real-time information can be operationalized into decision-support tools that enable earlier advisories, treatment adjustments, and risk communication.

■ **Application:** Serves as an authoritative reference for understanding HAB risks, management strategies, and regulatory frameworks. Useful for informing policy discussions, designing monitoring programs, and supporting communication efforts with stakeholders. Helps justify investment in monitoring, forecasting, and public advisory systems.

■ **Conclusion:** Operational HAB forecasting systems demonstrate how environmental information can be translated into actionable management tools with clear economic relevance.

■ **Monetized Value:** No, economic benefits implied through avoided health risks and treatment costs but not quantified.

Rouleau, T., Adkins, J., Fooks, J., Kornbluth, A., & Antolick, J. (2024). *Estimating the benefits of ocean color data in mitigating HAB events.* NOAA NESDIS 161. Silver Spring, MD: Global Science and Technology, Inc. https://doi.org/10.25923/hy61-tb09 *Publication type: Technical Report*

■ **Purpose:** Estimate the economic benefits of satellite-derived ocean color (OC) data for mitigating HAB damages in the U.S.

■ **Audience:** Oceanographers, remote sensing scientists, resource managers, and policymakers involved in satellite data applications and HAB monitoring.

■ **Geographic Range:** Continental U.S., including coastal and Great Lakes regions.

■ **Summary:** This report evaluates national HAB damages, estimated at ~$1.3 billion annually, and models how improved satellite ocean color observations could reduce these damages by approximately 5%, yielding around $65.1 million in annual economic benefits. The analysis combines county-level demographic and industry data with historical HAB occurrences to estimate avoided impacts from enhanced monitoring. The report also discusses how satellite-derived information can support earlier bloom detection, improve situational awareness, and enable proactive management actions such as timely advisories and targeted mitigation efforts.

■ **Application:** Demonstrates how investments in satellite data products like

ocean color monitoring directly support HAB management and mitigation decisions. Provides guidance for program planning, cost-benefit analysis, and prioritization of resources in satellite and HAB monitoring programs.

■ **Conclusion:** Satellite ocean color data offer substantial operational and economic value by enabling earlier detection of blooms, reducing HAB damages, and supporting cost-effective management interventions. The study quantifies benefits that can inform federal and regional investment decisions.

■ **Monetized Value:** Yes, national avoided damages enabled by improved ocean color data, ~$65 million annually (United States; modeled 5% reduction on a ~$1.3B baseline).

Newbold, S. C., Lindley, S., Albeke, S., et al. (2025). *Valuing satellite data for HAB early warning systems.* https://www.rff.org/publications/working-papers/valuing-satellite-data-for-harmful-algal-bloom-early-warning-systems/ *Publication type: RFF Working Paper*

■ **Purpose:** Quantify the economic value of satellite-based HAB early warning systems using stated preference methods.

■ **Audience:** Environmental economists, HAB managers, policy analysts, and satellite data program planners.

■ **Geographic Range:** United States (generalized modeling framework applicable elsewhere).

■ **Summary:** Using stated-preference choice experiments, this study estimates the monetary value of satellite-based HAB early warning information. Results show that households are willing to pay positive and statistically significant amounts (on the order of tens of dollars per household per year) for timely HAB alerts. When aggregated across affected populations, these Willingness to Pay estimates translate into millions of dollars in annual societal benefits, demonstrating strong economic demand for satellite-enabled HAB early warning systems.

■ **Application:** The findings provide quantitative economic justification for investment in satellite observations and HAB early warning systems. By directly linking forecast information to avoided damages and user benefits, the study supports benefit–cost analyses for satellite data programs and HAB forecasting infrastructure.

■ **Conclusion:** The study concludes that satellite-based HAB early warning systems deliver substantial economic benefits, reinforcing their role in proactive HAB management, public health protection, and efficient environmental decision-making.

■ **Monetized Value:** Yes, household willingness-to-pay (WTP) for timely HAB alerts; tens of dollars per household per year, aggregated to millions of dollars annually (United States; stated preference).

THEME 3

Decision Theory and Value of Information in HAB Management

Theme 3 papers are ordered to progress from theoretical and conceptual introductions of decision theory and Value of Information (VoI) to applied studies that quantify how improved information supports HAB management. The sequence begins with methodological primers that establish VoI concepts and decision-analytic frameworks relevant to environmental monitoring and uncertainty reduction. It then moves to studies demonstrating how these methods can be applied to HAB forecasting, early warning, and monitoring investments to assess whether additional data meaningfully improve management outcomes. Chronological ordering within clusters reflects the evolution from conceptual framing to operational application and policy relevance, showing how VoI approaches clarify when improved prediction or monitoring justifies its cost by explicitly linking information to changed actions and reduced expected losses.

Canessa, S., Guillera-Arroita, G., Lahoz-Monfort, J. J., et al. (2015). *When do we need more data? A primer on calculating the value of information for applied ecologists*. Methods in Ecology and Evolution, 6(10), 1219–1228. https://doi.org/10.1111/2041-210X.12423 *Publication type: Peer-reviewed journal article*

■ **Purpose:** Introduce Value of Information (VoI) methods to quantify whether additional data collection improves decision outcomes sufficiently to justify its cost.

■ **Audience:** Environmental scientists, resource managers, decision analysts, and economists involved in monitoring and adaptive management.

■ **Geographic Range:** Conceptual; applicable across environmental and ecological management contexts.

■ **Summary:** This paper provides a clear, accessible introduction to VoI concepts and demonstrates how monitoring data can be evaluated based on their expected contribution to improved decisions. The authors show how VoI can guide decisions about monitoring intensity, spatial coverage, and investment priorities, issues directly relevant to satellite observing system design.

■ **Application:** The VoI framework is directly transferable to satellite-based HAB monitoring and forecasting, where decisions must be made about the value of additional satellite coverage, resolution, or complementary observations.

■ **Conclusion:** VoI analysis provides a rigorous, decision-focused method for evaluating whether additional environmental information, such as satellite observations, justifies its cost.

■ **Monetized Value:** Partially, expected value metrics; monetization depends on application.

Bolam, F. C., Grainger, M. J., Stewart, G. B., et al. (2019). *Using the value of information to improve conservation decision making.* Biological Reviews, 94(2), 629–647. https://doi.org/10.1111/brv.12471 *Publication type: Peer-reviewed journal article*

■ **Purpose:** Synthesize Value of Information theory and demonstrate its application to environmental and conservation decision-making under uncertainty.

■ **Audience:** Environmental decision-makers, economists, conservation scientists, and policy analysts.

■ **Geographic Range:** Global and conceptual; includes examples and case studies from multiple ecosystems and conservation contexts.

■ **Summary:** This review provides an overview of VoI approaches, illustrating how the expected benefits of additional data or monitoring can be quantified and used to guide resource allocation. The authors discuss both theoretical frameworks and practical examples, including species management, habitat conservation, and

ecological monitoring, emphasizing the trade-offs between the cost of collecting information and the potential improvement in decision outcomes.

■ **Application:** Offers guidance for managers and scientists to determine when further data collection is warranted, how to prioritize monitoring efforts, and how to integrate uncertainty into conservation planning. The principles are directly transferable to evaluating the value of environmental observations, including satellite data used in HAB monitoring and forecasting.

■ **Conclusion:** VoI approaches improve transparency and efficiency in environmental decision making by explicitly linking uncertainty reduction to decision outcomes.

■ **Monetized Value:** No, conceptual synthesis of VoI methods.

Luhede, A., Freund, J. A., Dajka, J. C., & Upmann, T. (2025). *The value of information in predicting harmful algal blooms.* Journal of Environmental Management, 373, 123288. https://doi.org/10.1016/j.jenvman.2024.123288 *Publication type: Peer-reviewed journal article*

■ **Purpose:** Estimate the economic benefits of improved HAB prediction using Value of Information (VoI) theory to support management decisions.

■ **Audience:** Environmental scientists, oceanographers, ecological modelers, and resource managers interested in HAB forecasting, decision theory, and environmental economics.

■ **Geographic Range:** German North Sea (shellfish management case study).

■ **Summary:** Applies Value of Information (VoI) theory to calculate the decision value of improved HAB prediction for shellfish management in the German North Sea. The authors compute EVPI and imperfect-information metrics to compare current information with enhanced prediction, focusing on how uncertainty reduction influences optimal actions. Results show value is highest in high-risk settings where time-sensitive decisions (e.g., harvest timing, advisories) can avert costly missed events or unnecessary closures. Monetary values are not reported; benefits are expressed through VoI metrics indicating substantial decision improvements from uncertainty reduction.

■ **Application:** Demonstrates how additional ecological monitoring (e.g., zooplankton, nutrient levels) can improve early warning systems, inform shellfish management decisions, and reduce economic damages. The approach is transferable to other regions and aquaculture systems.

■ **Conclusion:** VoI provides a rigorous framework for quantifying the benefits of information in HAB management. Even without explicit dollar values, the analysis highlights substantial operational and economic advantages from improved prediction.

■ **Monetized Value:** Partially, economic value implied via VoI, but no dollar estimates.

Hoagland, P., Kirkpatrick, B., Jin, D., Kirkpatrick, G., Fleming, L. E., Ullmann, S. G., Beet, A., Hitchcock, G., Harrison, K. K., Li. Z. C., Garrison, B., Diaz, R. E., & Lovko, V. (2020). *Lessening the Hazards of Florida Red Tides: A Common Sense Approach*. Frontiers in Marine Science, 7, 538. https://www.frontiersin.org/journals/marine-science/articles/10.3389/fmars.2020.00538/full *Publication type: Peer-reviewed journal article*

■ **Purpose:** Provide policy-forward guidance emphasizing risk communication, monitoring continuity, and public notification as cost-effective red tide responses.

■ **Audience:** Policymakers, coastal managers, communicators.

■ **Geographic Range:** Florida Gulf Coast (generally applicable).

■ **Summary:** The authors argue that transparent, trusted information services should take precedence over control technologies given tourism and health sensitivities. This aligns with a VoI perspective: when uncertainty and stakes are high, timely and accurate forecasts/advisories can yield large welfare gains relative to cost. The piece also addresses social amplification of risk and the importance of consistent messaging.

■ **Application:** Governance rationale for sustained investments in HAB forecast and advisory systems.

■ **Conclusion:** Information clarity is a primary mitigation strategy for red tide.

■ **Monetized Value:** No; policy framework.

Lucas, K. M., Larkin, S. L., & Adams, C. M. (2010). *WTP for Red Tide Prevention, Mitigation, and Control Strategies: A Case Study of Florida Coastal Residents.* (Conference paper) https://www.researchgate.net/profile/Sherry-Larkin/publication/254388824_Willingness-to-Pay_for_Red_Tide_Prevention_Mitigation_and_Control_Strategies_A_Case_Study_of_Florida_Coastal_Residents/links/5408571d0cf2bba34c26fd3d/Willingness-to-Pay-for-Red-Tide-Prevention-Mitigation-and-Control-Strategies-A-Case-Study-of-Florida-Coastal-Residents.pdf

UF/IFAS EDIS (2010). *Strategies to Address Red Tide Events in Florida: Results of a Survey of Coastal Residents.* https://journals.flvc.org/edis/article/download/119294/117113/ *Publication type: Conference paper & Extension report*

■ **Purpose:** Elicit Willingness to Pay (WTP) for prevention/mitigation and for a beach conditions reporting service, indicating demand for information that reduces uncertainty and exposure.

■ **Audience:** State decision-makers, economists, coastal NGOs.

■ **Geographic Range:** Florida coastal counties.

■ **Summary:** Residents report positive WTP for information-heavy strategies, providing early evidence that the public values risk communication services. The EDIS report details preferences among prevention, control, and mitigation options and documents public knowledge of red tide. Together with newer WTP for airborne toxin forecasts, these studies support budget priorities for information/forecast services.

■ **Application:** Justifies allocating funds toward forecast-adjacent advisory and reporting products.

■ **Conclusion:** Public demand exists for information goods that reduce HAB risk.

■ **Monetized Value:** Yes, WTP estimates reported (stated preference).

Zahir, M., Su, Y., Shahzad, M. I., Ayub, G., Rahman, S. U., & Ijaz, J. (2024). *A review on monitoring, forecasting, and early warning of harmful algal blooms.* Aquaculture, 598, 738259. https://doi.org/10.1016/j.aquaculture.2024.738259 *Publication type: Peer-reviewed journal article*

■ **Purpose:** Review current methods for monitoring, forecasting, and providing early warning of HABs.

■ **Audience:** Oceanographers, ecological modelers, HAB managers, and decision-support researchers.

■ **Geographic Range:** Global; includes freshwater and marine systems.

■ **Summary:** This review synthesizes current approaches for HAB monitoring, forecasting, and early warning across freshwater and marine systems. It evaluates in situ sampling, satellite remote sensing, numerical models, and machine learning techniques, emphasizing the strengths and limitations of each. Although the paper does not provide monetized ($) estimates, it emphasizes that improved forecasting and early warning can reduce economic and health burdens by enabling earlier and more targeted management actions.

■ **Application:** Provides a foundation for developing decision-support systems and evaluating the value of additional information in HAB management. It supports the design of integrated monitoring and forecasting frameworks that enhance early warning capabilities for aquaculture operations, public health advisories, and ecosystem management.

■ **Conclusion:** Integrated data approaches improve information quality, reduce uncertainty, and enhance management effectiveness. While no direct monetary valuations are provided, the review underscores the practical value of improved HAB information for timely decision-making.

■ **Monetized Value:** No, conceptual value-of-information; not monetized.

THEME 4

Conceptual and Methodological Foundations for Valuing Satellite Information

In Theme 4, papers are organized from foundational and conceptual frameworks to applied analyses of satellite or environmental information valuation. The sequence starts with methodological and theoretical works that establish how environmental data, including satellite observations, can be monetized or assessed for decision-support. It then moves to applied studies demonstrating these approaches in specific contexts or missions. Chronological ordering within these clusters emphasizes the development and refinement of valuation techniques, highlighting how foundational concepts have informed more concrete applications over time.

Freebairn, J. W., & Zillman, J. W. (2002). *Economic benefits of meteorological services.* Meteorological Applications, 9(1), 33–44. https://doi.org/10.1017/S1350482702001044 *Publication type: Peer-reviewed journal article*

■ **Purpose:** Explain how meteorological information, including satellite-derived observations, generates economic value by improving forecasts and decision-making.

■ **Audience:** Meteorologists, economists, environmental decision-makers, and public-sector agencies responsible for forecasting services.

■ **Geographic Range:** Conceptual and international; examples drawn from national meteorological services.

■ **Summary:** This paper outlines the theoretical and practical basis for valuing forecast information, emphasizing the role of satellites as foundational data sources. The authors describe how forecast improvements translate into economic benefits through better planning, reduced risk, and avoided damages. The paper clearly distinguishes forecast accuracy from forecast value, providing a conceptual foundation widely used in environmental and Earth observation valuation studies.

■ **Application:** Although not HAB-specific, the framework directly underpins valuation approaches for satellite-based HAB forecasts and early warning systems by linking improved information to welfare gains and management outcomes.

■ **Conclusion:** Satellite-supported forecasting services generate economic benefits that substantially exceed their costs when forecast information is effectively integrated into decision-making processes.

■ **Monetized Value:** Yes, general economic benefit estimates discussed; framework supports monetization (not HAB-specific).

Macauley, M. K. (2006). The value of information: Measuring the contribution of space-derived Earth science data to resource management. *Space Policy, 22*(4), 274–282. https://doi.org/10.1016/j.spacepol.2006.08.003 *Publication type: Peer-reviewed journal article*

■ **Purpose:** Develop a conceptual framework for measuring the value of space-based Earth observation data as inputs to resource management decisions.

■ **Audience:** Environmental economists, satellite program planners, Earth scientists, and policymakers involved in evaluating the benefits of Earth observation systems.

■ **Geographic Range:** Conceptual and global; applicable across environmental management contexts.

■ **Summary:** This paper frames satellite-derived Earth science data as information goods whose value arises from improved decision-making rather than direct use. The author outlines pathways through which satellite observations reduce uncertainty, improve timing and targeting of actions, and generate economic benefits. While not HAB-specific, the framework explicitly addresses water resources, environmental monitoring, and hazard management. These contexts are directly relevant to satellite-based HAB forecasting.

■ **Application:** Provides a widely cited conceptual foundation for valuing satellite data used in HAB monitoring and early warning systems. The framework supports benefit–cost analysis and Value of Information approaches applied to satellite observing investments.

■ **Conclusion:** The value of satellite Earth observations lies in their contribution to better decisions and outcomes. Explicitly linking satellite data to management actions is essential for credible valuation and policy justification.

■ **Monetized Value:** No, conceptual framework for valuation is presented, but no empirical monetization.

RFF–NASA VALUABLES Consortium (2017–2023). *Final report and Impact-Assessment (IA) framework for valuing EO information (incl. HABs in California lakes).* Final report: https://media.rff.org/documents/RFF-NASA-VALUABLES-final-report.pdf ; IA explainer: https://www.rff.org/publications/explainers/value-of-science-106-the-valuables-impact-assessment-framework/ ; Program landing: https://www.rff.org/valuables/ ; Editorial w/ HABs case: https://www.resources.org/archives/windows-on-the-world-the-value-of-satellite-information-for-decisionmaking/ *Publication type: Program synthesis; methodological explainers; editorial overview*

■ **Purpose:** Provide a with/without data impact-assessment framework to quantify the value of satellite information by tracing how new data change decisions and outcomes (lives or dollars saved).

■ **Audience:** EO mission planners, economists, applied scientists, evaluators.

■ **Geographic Range:** Global methods with U.S. applications (incl. HAB-related recreation).

■ **Summary:** The framework specifies how to identify which choices change when data are available and how those choices translate into measurable outcomes—exactly the logic used in forecast valuation. The final report and resources establish common language, steps, and evidence standards for EO valuation communities. Published case studies include HABs and recreation in California lakes, demonstrating domain-specific application.

■ **Application:** Use the IA steps when framing VoI for HAB forecasts (define users/decisions, establish counterfactuals, quantify outcomes).

■ **Conclusion:** Credible valuation of satellite-enabled forecasts requires explicit decision links and counterfactual comparisons.

■ **Monetized Value:** Framework enables monetization; several case studies report monetary outcomes.

Kite-Powell, H. L., Colgan, C. S., Wellman, K. F., Pelsoci, T., Wieand, K., Pendleton, L., Kaiser, M. J., Pulsipher, A. G., & Luger, M. (2004). *Estimating the economic benefits of regional ocean observing systems*. Woods Hole Oceanographic Institution. https://apps.dtic.mil/sti/pdfs/ADA484010.pdf *Publication type: Technical Report*

■ **Purpose:** Develop a practical methodology to estimate the potential economic benefits of regional coastal ocean observing systems by quantifying how improved environmental information reduces uncertainty and leads to better decisions across user sectors.

■ **Audience:** Ocean observing system designers and program sponsors (e.g., NOPP), marine and environmental economists, coastal resource managers, and maritime transportation stakeholders who require defensible benefit estimates to inform planning and investment.

■ **Geographic Range:** United States coastal waters, analyzed through ten regions covering all U.S. coasts; framework is transferable to other regions with appropriate local parameters.

■ **Summary:** The report treats ocean observations as information goods that improve decision-making across diverse sectors, including recreational fishing and boating, beach recreation, maritime transport, search and rescue, spill response, marine hazards prediction, offshore energy, and commercial fishing. Benefits are calculated by comparing outcomes with and without observing system information, including avoided accidents, time savings, and operational efficiencies.

■ **Application:** Provides a transferable, sector-by-sector benefit estimation approach that agencies and regional associations can adapt to their specific observing architectures and user needs, supporting benefit–cost analyses and strategic design choices for integrated coastal observing systems.

■ **Conclusion:** Investments in observing systems generate substantial, monetizable economic benefits by improving decision quality across multiple sectors.

■ **Monetized Value:** Yes, benefits quantified via avoided costs and improved outcomes, totaling hundreds of millions of dollars annually nationwide (United States; amounts vary by sector and method).

Lauer, C., Conran, J., & Adkins, J. (2021). *Estimating the societal benefits of satellite instruments: Application to a break-even analysis of the GeoXO hyperspectral IR sounder.* Frontiers in Environmental Science, 9, 749044. https://doi.org/10.3389/fenvs.2021.749044 *Publication type: Peer-reviewed journal article*

■ **Purpose:** Estimate societal benefits of satellite instruments and evaluate whether benefits justify development and operational costs via break-even analysis.

■ **Audience:** Earth system scientists, satellite program planners, environmental economists, and decision-makers in satellite mission design.

■ **Geographic Range:** Continental U.S. (applicable globally).

■ **Summary:** Using the GeoXO Hyperspectral IR Sounder as a case study, the authors link improved environmental observations to societal benefits in areas like weather forecasting and air quality monitoring. The study uses a break-even framework instead of fully monetizing all downstream impacts.

■ **Application:** Highlights pathways where enhanced satellite information reduces uncertainty and improves decision-making, providing a practical framework for evaluating the value of new satellite missions.

■ **Conclusion:** Break-even analysis demonstrates how satellite systems can deliver management value even when full monetization of benefits is infeasible.

■ **Monetized Value:** No, break-even thresholds only (no explicit dollar monetization of downstream benefits).

Summary Conclusion

The literature reviewed here shows that harmful algal bloom (HAB) forecasts and satellite observations create substantial societal value by reducing uncertainty, improving situational awareness, and supporting timely management actions. Although the studies differ in scale, methodology, and geographic focus, they collectively demonstrate that information itself is a critical public good for environmental decision-making. Accurate, timely, and accessible HAB information leads to better outcomes for public health, fisheries and aquaculture, recreation, and water resource management.

Across marine and freshwater systems, satellite-enabled HAB forecasts are now credibly informing day-to-day decisions by managers and the public, from selective shellfish openings and targeted toxin testing in the Pacific Northwest to beach-level respiratory risk planning in Florida. These products reduce uncertainty in the dimensions that matter most, specifically where and when exposure will occur, allowing users to retime or relocate activities and enabling managers to prioritize sampling, advisories, and closures. Formal Value of Information assessments for the PNW HAB Bulletin demonstrate that program benefits exceed costs, while operational documentation illustrates an institutionalized decision pathway linking forecasts to management actions.

Methodologically, best practice Earth observation valuation frameworks emphasize comparing outcomes with and without information to isolate the value of data. Applied to HAB forecasting, this logic clarifies how improved observations change decisions and how those decisions translate into measurable outcomes, such as avoided illnesses, preserved recreation, and reduced monitoring effort. Decision theory and Value of Information approaches provide a consistent framework for identifying when additional monitoring or improved forecasts justify their cost, particularly in settings characterized by high uncertainty and high consequences.

The broader literature on valuing satellite information reinforces these conclusions. Environmental and Earth observation data have value because they improve decisions that affect people, resources, and economies. Across all themes, the evidence supports the conclusion that investment in HAB forecasting and satellite monitoring is both scientifically justified and economically beneficial. The research shows that better information leads to more proactive management, reduced risks, and substantial societal benefits. Future progress will depend on continued integration of economic valuation, user engagement, and decision-analytic methods to ensure that HAB information systems remain relevant, actionable, and aligned with management needs.


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