Science-Informed Decision Making: Translating Science

Dr. Sabine E. Apitz
SEA Environmental Decisions, Ltd.
Little Hadham, UK
+44 (0)1279 771890; drsea@cvrl.org

©2021 Sabine E. Apitz; SEA Environmental Decisions Ltd.
Both natural and anthropogenic processes may increase or decrease human well-being.

Ecosystem disservices / threats
- Pests
- Disease
- Natural toxins
- Drought
- Floods
- Landslides
- Global warming
...

Ecosystem services (benefits)
- Food
- Freshwater
- Wood & fibre
- Natural medicines
- Disease regulation
- Climate regulation
- Erosion control
- Flood regulation
- Water purification
- Recreation
- Aesthetics
- Spiritual values
...

Human well-being
- Basics for a good life
- Health
- Security
- Good social relations
- Freedom of choice

Anthropogenic inputs
- Chemical products, land and water scape alteration, biophysical change...
Both natural and anthropogenic processes may increase or decrease human well-being. Ecosystem disservices / threats include pests, disease, natural toxins, drought, floods, landslides, and global warming. Anthropogenic inputs involve chemical products, land and water alteration, and biophysical change.

Ecosystem services (benefits) include food, freshwater, wood & fibre, natural medicines, disease regulation, climate regulation, erosion control, flood regulation, water purification, recreation, aesthetics, and spiritual values. Human well-being involves basics for a good life, health, security, good social relations, and freedom of choice.

ES-based and other assessment can underlie decision-making, identifying trade-offs. Ultimately, balancing trade-offs is normative – our role is to support science-informed societal decision making.
Effectively linking the science to the decision context requires that decisions and scenarios are clearly articulated and scoped. From Apitz (2013) IEAM 9(2):414-430.

Where are we? What are baseline conditions?

Where do we want to be?
Environmental risk questions

- What are the risk and vulnerabilities?
- Are we protecting against everything?
- At what spatial and temporal scale?
- What is controllable, what is not?
- Are we developing preventions, tracking changes, selecting responses?

Sustainability questions

- What is it you want to sustain?
- Who benefits?
- For what period of time will benefits be conveyed?
- At what cost (to whom)?
- Who decides?
The Socio-ecological system is complex and interconnected

“Sustainable” Decision making

- There are a range of criteria by which management decisions can be made
  - Using different criteria will yield different options and rankings
- Whether something is “sustainable” or not depends on perspective
  - The best management option depends on the decision criteria selected, and how the question is scoped and scaled
- We manage the environment to sustain ecological, economic and social objectives
- Keys to success are engagement, transparency, flexibility and adaptiveness

From Apitz 2015
Protecting local ecosystems without changing consumption simply offsets biodiversity impacts.

Where biodiversity is impacted

Where consumption takes place

From Marques et al. 2019 doi: 10.1038/s41559-019-0824
An evolution of the stakeholder relationship (from personal observations over decades)

- I delivered a thick report. Why aren’t they using my data?
  - Science-decision disconnect

- We are logical, the “public” is not
  - Misunderstanding of role of assessment in the decision process

- Learning how to manage the stakeholder “challenge”
  - Stakeholders as menace to be managed

- But we addressed all the important issues. Why aren’t you grateful?
  - Paternalistic technocrats

- Stakeholder knowledge over technical evaluation
  - Over-correction

- Technical/public Partnership – trans-disciplinary working
  - Science in support of societal decision making
  - Technical role is to educate, inform, listen, respond, integrate and communicate
  - Balanced role of technical expertise and public input (but expectations must be managed within the reality of the statutory process)
A spectrum of 5 forms of working

1. **Holistic approach; New outcome**
2. **Synthesising for new knowledge**
3. **Working together additively**
4. **Awareness of other disciplines**
5. **Single discipline**

Approaches for determining stakeholder priorities

- Identify Stakeholder Groups (SGs) - Stakeholder map
  - Documentation of SG values
  - SG outreach (surveys, workshops, facilitated outreach)

Tools to avoid bias:
- Neutral parties, snowball sampling, iterations, comparisons over time or to other studies, transparency

Inferred Priorities

Elicited Priorities

SG Priorities – Relative importance of impacts
Approaches for determining stakeholder priorities

Identify Stakeholder Groups (SGs) - Stakeholder map

- Documentation of SG values
  - Inferred Priorities
  - SG outreach (surveys, workshops, facilitated outreach)
  - Elicited Priorities

Identify Stakeholder Groups (SGs) - Stakeholder map

- SG Priorities: Relative importance of impacts
- SG Priorities: Trade-offs can then be weighted in terms of differing priorities, e.g., health, sustainability, safety, fairness...

If science is to be helpful in informing societal decisions, it is essential that technical values, objectives, and concerns are aggregated. Tools to avoid bias: neutral parties, snowball sampling, iterations, comparisons over time or to other studies, transparency.
Sediment frameworks focus on different drivers

Evaluating sediments to manage in-place risks

Evaluating sediments to manage risks to water

Evaluating dredged sediments to determine disposal options

These are not interchangeable. Though science-based, each measure, standard and step in these frames requires POLICY choices – these blend science, trans-science and policy.
When a conceptual approach for integrating data, models and decisions is clearly laid out, decisions and recommendations can be negotiated and communicated.
When a conceptual approach for integrating data, models and decisions is clearly laid out, decisions and recommendations can be negotiated and communicated.
There are a number of potential pathways for contaminant transport in sediments. The magnitude and direction of these fluxes controls both risk and recovery potential. An understanding of these processes will inform conceptual site models (CSMs), put biological observations in context and design management strategies.
PRISM Program Integrated Field-Measurable Flux Parameters into Adapted Theoretical Models

$$\sum Flux = F_D + w(c_{aw} - c_{ow}) - RH_a + v_e (K_e, \tau, \tau_c) (c_{as} - c_{os}) + v_s (c_{ss} - c_{as})$$
PRISM Program Integrated Field-Measurable Flux Parameters into Adapted Theoretical Models

It was critical that the tools and measures of each partner led to their own objectives and papers, whilst also having a “handshake” via which data could feed into the decisions for which the work was funded.

In many projects, this faces resistance, regardless of funding purpose – applications and integration are seen as beneath “pure” work.
Comparing flux pathways - Inserting field measurements into models – PAHs

Ongoing inputs from sedimentation overwhelm any fluxes out of sediments
## Interpretation of Field-Based Mobility Indices: Risk Vs. Recovery

- Indices indicate relative magnitude of fluxes
- Risk managers must then balance risk with recovery potential

<table>
<thead>
<tr>
<th>High Score</th>
<th>Risk</th>
<th>Recovery</th>
<th>Example Strategies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diffusion Index</td>
<td>Contaminant flux to biota</td>
<td>Contaminant attenuation</td>
<td>Reactive/sorptive/impermeable caps, thicker cap, Predict recovery</td>
</tr>
<tr>
<td>Bioirrigation Index</td>
<td>Contaminant flux to biota</td>
<td>Contaminant attenuation</td>
<td>Barrier</td>
</tr>
<tr>
<td>Advection Index</td>
<td>Contaminant flux to biota, Contaminant flux to sediments from offshore</td>
<td>Contaminant attenuation, Contaminant flux to sediments from offshore</td>
<td>Reactive/sorptive/impermeable caps, Groundwater interdiction, Predict recovery,</td>
</tr>
<tr>
<td>Erosion Index</td>
<td>Contaminated particle transport, particle spreading, Exposure to biota</td>
<td>Mixing/dilution of contaminants, Enhanced degradation (aerobic)</td>
<td>Removal, containment, Predict bioremediation</td>
</tr>
<tr>
<td>Sedimentation Index</td>
<td>Continued input (if contaminated)</td>
<td>Burial (if clean)</td>
<td>Control source, Predict recovery</td>
</tr>
<tr>
<td>Bioturbation Index (Quant. Method TDB)</td>
<td>Exposure to biota, Upward mixing</td>
<td>Dilution, $O_2$, nutrient delivery</td>
<td>Barrier</td>
</tr>
<tr>
<td>Biodegradation Index</td>
<td></td>
<td>Loss of contaminants</td>
<td>Enhance biodegradation, Avoid blocking $O_2$</td>
</tr>
</tbody>
</table>

Managing in situ sediment-contaminant fate
Linking endpoint protection to service protection – impacts of “stressor” depend on location, endpoint and conditions

Pathways of desirable (green) and undesirable (red) impacts of fine-grained sediment on aquatic endpoints, and associated ecosystem services
Pathways of desirable (green) and undesirable (red) impacts of fine-grained sediment on aquatic endpoints, and associated ecosystem services.

Whether something is harmful or beneficial can be context-specific — which risks and impacts are most important to stakeholders?
Managing soil/sediment balance in catchment

Addressing the relative impacts of these multi-dimensional pathways lends itself to tools such as regional risk models.
What is the vision of site use?

Risks, opportunities and trade-offs of management alternatives differ, depending upon the vision of site use or re-use.
What do we want to achieve?

How do we implement and optimise?

What are the effects?

Are we done?

How do we adapt?
To inform decisions, a coherent set of criteria are*

- **Exhaustive**
  - Allow a clear delineation between options

- **Cohesive**
  - Options that rank higher on one criterion should be preferred

- **Clear**
  - Linked to decisions, in scientific terms and in the minds of decision makers

- **Not** redundant – avoiding bias and double-counting

- **Relevant**
  - Meaningful to the actual decision process

Technical aspects of alternatives can be translated in terms of stakeholder values, and scored to inform decisions.

What issues that stakeholders value are affected by decision (criteria)?
- Environmental
  - Ecological Health
  - Habitat
    - Resilience
    - Green Remedy
- Economic
  - Economic Vitality
  - Jobs
  - Infrastructure
  - Cost-Effectiveness
- Social
  - Quality of Life
  - Fairness
  - Recreation
  - Health & Safety

How are they affected (indicators)?
- Resilience
  - Re-contamination, natural attenuation
- Vulnerability to extreme events, disturbance

How can this be quantified (metrics)?
- Upstream inputs vs cleanup goals, source control
- Volumes/levels in-place
- Flood and storm models
- Design criteria
- Environmental security
Aggregation vs trade-offs

- Aggregation of metrics into a single parameter simplifies outputs, allowing for simple ranking of alternatives
  - However, this approach embeds a number of value decisions
  - Masks complexity

- Trade-off approaches allow stakeholders to see what “drives” differences
  - The effects of differing priorities (value decisions) can be seen
  - However, outputs can seem complex

- There is a place for both approaches, which can be driven by similar data

- Ideally, it should be possible to “unpack” or aggregate outputs, as needed
Same alternatives, same data, different viewpoints and aggregation – perspective affects how one prioritizes alternatives.

Scored in terms of regulatory criteria

Scored in terms of community impact

Source: SEA; work in progress, Tier 2 adaptation of PHSP tool
ES concepts can be applied in various ways, depending upon objectives and project cycle step.

Case 2: Western Scheldt
- Full-cycle (baseline, prospective, monitoring, evaluation, adaptation) selective, non-explicit ESA to design beneficial, synergetic dredged material disposal and management
- WwN to enhance habitats and optimize hydrologic function, balancing multiple goals
- Broader ES consideration, e.g., water quality regulation, could enhance benefits

Case 4: Sigmplan
- Baseline ESA identified multiple objectives; prospective ESA informed conceptual design phase
- Monetary societal cost-benefit analysis sought highest net benefits, considering flood safety, navigation, agricultural, regulation and cultural services
- Alternative chosen differed from choice based upon flood control alone, demonstrating benefits of early ES consideration

Case 5: Nicaraqua Canal
- Baseline ESA, then prospective ESA examining impacts of selected design to identify mitigation measures
- Qualitative assessment, as part of ESIA
- Earlier and explicit consideration of ES in design phase may reduce impacts and the need for mitigation

Case 7: Coffs Harbour
- Prospective, non-explicit ESA informed multi-criteria assessment to balance "use values" (safety, recreation and economics) of shoreline protection plans
- Values were gathered through early, multi-disciplinary stakeholder engagement
- More explicit consideration of potential ES may have broadened criteria

Applying ES concepts in the water transport infrastructure sector - defining the decisive role of ES in project helps guide application.

<table>
<thead>
<tr>
<th>Options</th>
<th>Feasibility</th>
<th>Effectiveness at reducing risk</th>
<th>Overall Effectiveness</th>
</tr>
</thead>
<tbody>
<tr>
<td>FT1</td>
<td>FT2 FT3</td>
<td>FT4</td>
<td>FT1 FT2 FT3 FT4</td>
</tr>
<tr>
<td>FT2</td>
<td>FT3 FT4</td>
<td>FT1</td>
<td>FT2 FT3 FT4 FT1</td>
</tr>
<tr>
<td>FT3</td>
<td>FT4 FT1</td>
<td>FT2</td>
<td>FT3 FT4 FT1 FT2</td>
</tr>
<tr>
<td>FT4</td>
<td>FT1 FT2</td>
<td>FT3</td>
<td>FT4 FT1 FT2 FT3</td>
</tr>
</tbody>
</table>

**Rankers - effectiveness**

**Stoppers - infeasible**

Screening contaminated dredged material management options.
Pilot-scale evaluation of the ecosystem consequences of habitat creation using dredged sediment

1. erosion/sedimentation
2. currents and solid transport
3. bioaccumulation
4. toxicity
5. partitioning
6. Mercury cycling
7. effects of Mercury on phytoplankton
8. effects of Mercury on microbial communities in water
9. effects of Mercury on microbial communities in sediment
10. effects of Mercury in sediments and water
11. effects of Mercury on colonization
12. effects of Mercury on macrobenthic communities
13. effects of Mercury on foraminifera and ostracods as environmental indicators

Image courtesy of Cristina Nasci, Thetis SpA
Pilot-scale evaluation of the ecosystem consequences of habitat creation using dredged sediment

1. erosion/sedimentation
2. currents and solid transport
3. bioaccumulation
4. toxicity
5. partitioning
6. Mercury cycling
7. Effects on phytoplankton
8. Microbial communities in water
9. Microbial communities in sediments and water
10. Colonization
11. Macro-benthic communities
12. Pathogens in sediments and water
13. Salt marsh colonization

Measures linked to ecosystem service providing units (SPUs) and regional objectives – SPUs tracked before and, over time, after habitat construction

Image courtesy of Cristina Nasci, Thetis SpA
Multiple lines of evidence can be integrated to look at exposure and effects of habitat construction. Almost a year later, there is evidence of recovery. Communities are resilient.
Ecosystem Service trade-offs for differing management alternatives

Comparing habitat restoration to off-site treatment

When we look at these disparate endpoints, trade-offs – both opportunities and unintended consequences – become apparent

Ecosystem impacts of dredged material options

ES impacts of pest management strategies
Tools and approaches can be complementary. They each have strengths and weaknesses – they are framing tools, and can be adapted as needed.
How do we translate science to better manage ecosystems?

- Be connected
  - Ecosystems are

- Be skeptical and transparent
  - The devil is in the details

- Be uncertain
  - The myth of certainty undermines credibility

- Be promiscuous
  - Use the best tools for the question at hand

- Be humble
  - Even simple systems have the capacity to surprise us

- Be adaptive
  - Monitor, adapt, respond and communicate
Linking multi-criteria evaluation to societal decision making

- Whether explicitly addressed or not, all management and policy choices result in trade-offs
- Technical assessments *can* provide a thread by which cross-sectoral decisions can be informed
  - There are a range of tools available; these can be tailored to decision at hand
- To support sustainability it is essential to quantify how actions will affect a range of services, values and objectives (and populations) in space and time
  - Over-simplification, including monetisation, hides complexity
  - The approach should fit the application
- Technical assessments should be linked clearly to stakeholder values and priorities
  - This recognises that our technical role is to *support* societal decisions
  - This requires clarity, transparency and relevance of approaches