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A new protocol for monitoring operational outcomes of environmental management in commercial forestry plantations

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ABSTRACT

Environmental degradation is a global phenomenon with a high likelihood of influencing human quality of life. Effective management responses are needed to achieve societal goals of sustainability. We develop here a new monitoring protocol (Management Check: MATCH) that comprehensively evaluates management outcomes at the operational level. Using the Driver-Pressure-State-Impact-Response (DPSIR) framework, we identified pressures influencing ecosystem integrity inside conservation corridors and commercial compartments of a timber production landscape mosaic. They were 1) domestic livestock grazing (the only exogenous pressure), 2) fire management, 3) invasive alien plants (IAPs), and potential soil erosion from two sources: 4) roads, and 5) harvested timber compartments. We assessed the effects of these on wetland and stream buffers. Environmental incidents accounted for more serious management issues (e.g. oil spills). Management responses were systematically unpacked into point-form questions, which formed the building blocks of our monitoring protocol. We assessed management in twelve plantations in KwaZulu-Natal, South Africa. Answers were compared with Best Operational Practice (BOP), and reworked into a Weighted Index of Compliance (WIC) per section. We found that there was poor management of livestock grazing, but good management of IAPs, roads, and timber compartments. Management of wetland and stream buffers was very good. Fire management presented problems linked to lack of direct effects, measurable at the spatial and temporal scales of operations. We discuss operational outcomes within their respective legislative frameworks, and suggest ways of improving management operations, where needed. MATCH is the first monitoring protocol to comprehensively assess environmental management of commercial forestry at the operational level, and to clearly translate operational activities into measurable progress towards strategic goals. In doing so, MATCH breaks down silos and builds bridges for efficient environmental management in dynamic socio-ecological systems. Moreover, the principles developed here can be applied to build tools that help manage major risks in other economic sectors too. Overall, MATCH strengthened strategic and informed action, which is necessary at multiple levels of an organization, to combat major societal risks, such as environmental degradation.

1. Introduction

Biodiversity loss and collapse of ecosystem processes is a key risk to human life (World Economic Forum, 2019). The Global Risks Report (2019) has included this risk for the first time as one of the top ten global risks, as it is likely to occur and have huge impacts on human life via the pathways of environmental degradation and climate change. At the turn of the century, environmental degradation had already affected more than half of the world’s ecosystems (Millennium Ecosystem Assessment, 2005). It is imperative for human well-being to stop further damage to natural ecosystems.

Environmental degradation is the deterioration of ecological condition, as well as loss of biodiversity and ecosystem function and services due to the synergistic effects of anthropogenic pressures and natural processes (e.g. pathogens and insect outbreaks), which may be exacerbated by climatic cycles. It is a complex, multidisciplinary problem without clear boundaries, as underlying causes of degradation need not be on-site to have an effect. Degradation often results from indirect, synergistic impacts at the nexus of socio-economic change and biophysical constraints (Hoffman and Todd, 2000; Millennium Ecosystem Assessment, 2005). The complexity of environmental degradation further plays out in the constant adaptation and changing importance of
different elements in this socio-ecological system, which renders ineffective solutions that focus on relatively simple cause-and-effect relationships (Lundberg, 2005; Svarstad et al., 2008; Tscherning et al., 2012). We need to understand the multi-faceted nature and complexity of environmental degradation to formulate effective responses to stop it (Niemeijer and de Groot, 2008).

The DPSIR (Driver-Pressure-State-Impact-Response) framework is useful for understanding change in socio-ecological systems. The framework is widely used, with recent advances in multi-national marine environments (e.g., Elliott et al., 2017). Oesterwind et al. (2016) define Drivers as superior complex phenomena governing the direction of ecosystem change, and can be either of human or nature origin. Anthropogenic drivers usually fulfill fundamental societal needs (e.g. food, fiber, and clean water), while natural drivers are great forces (e.g. earthquakes, severe droughts, or floods) independent of human activities. Drivers employ certain activities as mechanisms (or Pressures) to change the State of the environment. This has a certain Impact on human welfare, which elicits societal Responses to correct the relevant problems. Responses are all management actions seeking to reduce or prevent unwanted change or to develop a positive (desirable) change in the ecosystem (Oesterwind et al., 2016). Therefore, management responses can protect or aid recovery of ecosystem state, and they can mitigate Impacts on societal wellbeing (e.g. piped water for downstream users to mitigate the effect of damming a free-flowing river), or they can reduce the prevalence, intensity or direction of Pressures (Cormier et al., 2019; Gabrielson and Bosch, 2003). Moreover, they can function at different levels of governance (i.e. international to national to local), and in different departments (e.g. conservation vs. commercial operations) within an organization. To be effective and avoid the creation of information silos and intervention islands, there needs to be vertical integration from international treaties to national legislation to local management, as well as horizontal integration between conservation initiatives and commercial operations, with feedback loops to gauge and improve effectiveness of the management system over time (Cormier et al., 2019).

Defining boundaries of social-ecological systems is important for using the DPSIR framework (Svarstad et al., 2008). The boundaries can concur with the extent of Pressures, Impacts, or Responses, which gives rise to a diversity of applications. Also, depending on the boundary, there will be endogenous pressures that originate within, and exogenous pressures (e.g. ocean acidification or effluent from a dairy farm) that originate outside the system (Elliott, 2011). While management addresses the root causes, as well as consequences of endogenous pressures, it only addresses the consequences (or symptoms) of exogenous pressures (Elliott, 2011). Addressing root causes of exogenous pressures would imply shifting the boundaries to include source of the Pressure, which might be immediately feasible sometimes (e.g. dairy effluent), but not always (e.g. ocean acidification).

Adaptive management also takes place within these boundaries. When it proceeds in a structured and stepwise manner, adaptive management reduces uncertainty around the selection of best management practices for that system over time (Allen and Gunderson, 2011). Steps in the adaptive management cycle include problem assessment, formulation of plans, implementation of plans, and then analysis and adaptation to improve management efficiency of the overall system (Conservation Measures Partnership, 2019). Among these steps, there is a progression of management questions (e.g. what to do → was it done → was it effective), which influence data requirements. Monitoring should provide the types of data necessary to inform learning and adaptation in the adaptive management cycle (Allen and Gunderson, 2011; Murphy and Weiland, 2014). It follows that monitoring programs should be aligned with these data requirements, and should go beyond just ecological monitoring (McDonald-Madden et al., 2010), especially in ecosystems where there is a known time lag between onset (or removal) of pressures and eventual ecological responses. We need a complementary approach specifically focusing on management measures to shorten response times from problem detection to effective management solutions.

Management is guided by a hierarchy of targets, from 1) strategic plans, with long-term goals set by the governance body of an organization, 2) management controls focusing on medium-term objectives, and 3) operational controls that concern day-to-day activities and whether they comply with norms and standards (Ackoff, 1996; Cormier and Elliott, 2017). Where targets are fully aligned, it is necessary to achieve operational outcomes to reach management objectives in pursuit of strategic goals (Poister, 2010). Moreover, a regression from strategic goals to operational outcomes changes how SMART (Specific, Measurable, Achievable, Relevant, and Time-bounded) management measures can be (Cormier and Elliott, 2017), because each step represents a reduction in time frame (e.g. 20-year to 5-year to annual plans), an increase in level of detail, and a change from guiding directives to specific actions. It follows that to measure progress towards strategic goals, the focus of management measures should be at the level of operational outcomes.

The societal need for fiber is mostly met by timber harvested from commercial forests. Globally, indigenous trees are the primary source of harvested timber in Europe, Canada and the USA, while non-native (or alien) trees dominate in South Africa, parts of South America and the UK (Castro-Díez et al., 2019). The environmental risks and impacts associated with commercial forestry are widely acknowledged, and mitigated using a range of contextually-relevant sustainability measures. For example, the emphasis is on restoring degraded Atlantic forest in Brazil (Rodrigues et al., 2009), and maintaining mosaics of different plantation forest types in Europe (Ferre-Smith et al., 2019) and corridors juxtaposed with alien tree plantations in South Africa (Samways and Pryke, 2016). These measures feed into forest certification schemes (e.g. Forest Stewardship Council (FSC) or the Programme for the Endorsement of Forest Certification (PEFCC), which benefits forestry companies by securing public confidence, maintaining or increasing market access, and improving management effectiveness (Araujo et al., 2009). An integral part of forest certification schemes is environmental monitoring programs and internal auditing systems, with pre-approved third-party auditors to validate findings, to assess whether risks and impacts are adequately addressed. Monitoring programs typically focus on indicators of ecological state (e.g. soil health), risk (e.g. soil exposure) and impact (e.g. soil erosion), while audits mostly concern the execution of management actions needed to address these concerns. All certified forests and plantations will have such monitoring and auditing systems in place, although differing in level of detail. The problem is that they remain as disjoint data packages that are difficult to manage and holistically integrate into the management system.

In South Africa, commercial forestry is highly regulated, in terms of legislation, industry guidelines, International Organization for Standardization (ISO) standards, and voluntary forest certification schemes (Forestry Industry Environmental Committee, 2017). Legal compliance sets the minimum standard for environmental management, but guidelines for Best Operational Practice (BOP) build on this legal minimum to form a higher standard at industry level (Forestry Industry Environmental Committee, 2017). The contextually-relevant solution to sustain forest biodiversity in South Africa is a mosaic of commercial timber compartments and large-scale conservation corridors of natural or semi-natural habitat, with these corridors improving the permeability of the production landscape to biodiversity (Samways and Pryke, 2016). These require research and ecological monitoring programs that make management recommendations based on biodiversity patterns, but there are no complementary approaches to assess the enactment of these recommendations and to holistically assess management responses to risks and impacts of commercial forestry in the country.

The aim here is to develop a new monitoring protocol at the operational level for environmental management in commercial forestry, South Africa, as a novel approach towards assessing management operations that go beyond simply production, and consider biodiversity
conservation, maintenance of historic ecological function, all framed in a socio-ecological context. An earlier study, using the DPSIR framework to analyze the socio-ecological system represented by timber production mosaic landscapes, identified several medium-term management objectives to address the prevailing pressures in these systems (Samways et al., 2010). Our first objective here is to unpack these management objectives into operational outcomes that need to be achieved to reach long-term strategic goals. We phrased these outcomes as point-form statements and questions to assess three critical steps in the adaptive management cycle, i.e. formulating plans, implementing plans, and assessing effectiveness of implemented practices. Another target is the development of a user interface for the implementation of the protocol. For this purpose, we used and evaluated the protocol in commercial forestry plantations in two regions to identify management gaps that hinder achievement of management objectives. Finally, we discuss the effects of legislation, and practical constraints to effective environmental management. Having a monitoring protocol that translates operational outcomes into progress made towards strategic goals provides the link between on-the-ground managers and strategic decision makers, which is necessary to comprehensively manage the environment towards goals in dynamic and connected socio-ecological systems.

2. Methods

2.1. Identifying pressures and management responses

The need for a measure of management effectiveness in timber production landscapes, and the steps necessary to develop such a protocol was the result of collaboration among the forestry industry, independent environmental consultants, and a university research group. A workshop was held with one postdoctoral researcher, six independent ecologists, and four industry-employed environmental specialists from the same major forestry company. Each participant had specialist experience in a specific field, and recent working experience with the commercial forestry sector. The fields of expertise represented at the workshop were 1) state and management of grasslands, wetlands, and streams/rivers, 2) state and management requirements of populations of threatened and protected species, and 3) conservation planning to steer conservation effort to where it is most needed.

Together, workshop participants identified endogenous and exogenous pressures influencing ecological integrity inside plantation boundaries, which concurred with an earlier study on the topic (Samways et al., 2010). There was one exogenous pressure, 1) grazing by cattle belonging to neighboring human communities. The endogenous pressures mostly confined to within plantation boundaries were 2) fire regimes, 3) invasion by alien plants (IAPs), and soil erosion that was split according to origin, 4) roads, and 5) commercial timber compartments (Table 1). The width and integrity of 6) wetland and stream buffers were selected as indicators of ecosystem state at the landscape spatial scale. Ancient peatlands confined to the low-lying northeastern Zululand region were included as a special case of high-risk wetlands requiring special management attention. Moreover, borrow pits (i.e. sources of gravel for road maintenance) were included as a special management case for the road section. Finally, based on their practical experience, industry-employed specialists motivated for the inclusion of a section on 7) environmental incidents that specifically involve record-keeping and timeous interventions around more serious management contraventions (e.g. oil spills, poaching, illegal dumping, and sand mining). These seven themes formed the different sections in the monitoring protocol of management measures. Each section was scored separately using the methods outlined below in Statistical Analyses.

The system boundary was defined as the cadastral boundaries of all plantations owned or managed by the forestry company. The size of plantation holdings was >250 000 ha spread out over a large area (~460 km × 250 km). It included several vegetation types and threatened ecosystems (Appendix 1). Moreover, the management standard of

| Pressures | Responses | State |
|-----------|-----------|-------|
| FIRE: Annual burning and fire exclusion both cause ecological losses in grassland | Change the fire regime. In addition to fire protection, incorporate ecological requirements for grasslands and grassy wetlands into fire management. | |
| Uncontrolled GRAZING by livestock owned by neighboring human communities | Reduce grazing pressure by enforcing compliance with recommended stocking rates. | There are annual assessments available for all IAP species and their cover abundances for all conservation areas in all plantations. |
| INVASIVE ALIEN PLANTS (IAPs) outcompete indigenous flora and change ecosystem composition, structure and function | Effectively control IAPs so that there is a year-on-year decline in mature plants, and an increase in weed free areas. | |
| SOIL EROSION from roads and borrow pits | Design and manage road infrastructure, especially crossings and drains, to avoid erosion and sedimentation of natural ecosystems | |
| SOIL EROSION from commercial timber compartments | Reduce water volume and flow rates, especially in steep and other sensitive areas. Time harvesting and silvicultural activities to limit soil exposure during wet and windy periods. | |
| Excessive WATER UTILIZATION by commercial timber compartments influence health of freshwater ecosystems, including ancient peatlands | Wetland delineation followed by clearing of timber trees from temporary and permanently wet zones (DWAF, 2005). Management of fire and grazing regimes, and control of IAPs to aid recovery of ecosystems. | Stream and wetland buffer width and integrity. Indicators of degradation are bare ground cover, basal cover, and cases of sedimentation. |
| ENVIRONMENTAL INCIDENT reports of more serious contraventions with BOP (e.g. oil spills) | Detailed reports, and timeous interventions to mitigate environmental impacts. | |

Table 1 Management responses to major pressures inside timber production mosaic landscapes.

This forestry company aligned well with national guidelines (Forestry Industry Environmental Committee, 2017), which means that management objectives and operational controls here could probably serve as a reference point for understanding management in other commercial plantations in SA.

From here onwards, all stakeholders involved in subsequent phases of the project were employed by that forestry company. We reconstructed management responses inside the system boundary into point-form operational outcomes with the help of environmental specialists. Operational outcomes were phrased as questions or statements that qualitatively assessed planning, implementation, and effectiveness of management practices (Appendix 2). This is similar to Plan-Do-Check-Act, an ISO-endorsed approach for continually improving management quality (ISO, 2015). Operational outcomes addressed causes and consequences for endogenous pressures (fire, IAPs, and soil erosion), but only consequences for the exogenous pressure of livestock grazing.

Much time was invested in the development of the question content, as each question had to be unambiguous (i.e. with only one meaning), and aligned with BOPs for the industry and company. Questions built on one another to turn simple ideas into management applications suited to the complexity of the system.
BOPs are the operational outcomes needed to address broad objectives set by the South African forestry industry (Forestry Industry Environmental Committee, 2017) in collaboration with conservation authorities, to achieve strategic goals of sustainability. However, the specific practices considered best to address these objectives were the result of learning through trial-and-error, as a product of adaptive management by the major forestry company.

These questions formed the building blocks of Management Check (MATCH), a monitoring tool to check how compliant operational outcomes were with BOP. Using MATCH, it is possible to identify and direct attention to management gaps in current operations, and this was for all major pressures in timber production systems. Strong feedback loops characterized the development and testing phases of MATCH, with emerging problems identified and addressed in collaboration with the industry throughout the process. An important point from a development point of view, is that MATCH was designed to fit in with, but also complement existing structures. It aligns with auditing tools and monitoring programs that inform key points in the adaptive management cycle. However, MATCH is key to this cycle, because it is the only tool to simultaneously consider management of all major pressures in timber production landscapes, to close the loop from management recommendations (what to do) to operational outcomes (what was done), and to use progress made at operational level as a measure of progress made towards achieving strategic goals.

2.2. Industry requirements for MATCH

The industry needed a monitoring protocol that is sensitive while yielding data in a format that can be rapidly analyzed. Generating new data can require substantial investment in time and money. To circumvent these constraints, we used primarily closed-ended questions with predefined answers (‘Yes’, ‘No’, ‘Sometimes’ and ‘Not applicable’) on Google Forms, which interfaces automatically with Google Sheets. BOP was defined for each of the 170 questions, and consequently reviewed by an environmental team of four people, which collectively had ~50 years of relevant experience. Also, each question was weighted (1–4) based on risk (i.e. likelihood to occur) and the magnitude of their potential impact if not managed well. In addition, there were 17 open-ended questions, which were not weighted or directly compared with BOP. Rather, they provided further insight into challenges and constraints to environmental management, and facilitated learning from successes and failures.

We involved two environmental specialists to test MATCH in two ecoregions (Zululand and the Midlands) in KwaZulu-Natal province, South Africa. Foresters implement the environmental management plan in plantations, while environmental specialists oversee environmental management and risk mitigation at regional level. We involved these specialists (instead of foresters) to standardize data quality among different plantations within a region. Each specialist was tasked with assessing the management inside six Work Plan Units i.e. a term used to refer to a cluster of plantations managed by a single forester. (From here onwards, we use the term ‘plantations’ to refer to WPUs.) The twelve plantations were spaced far apart, i.e. ~170 km from north to south and ~250 km from east to west (Fig. 1). The same set of BOP guidelines remained applicable throughout the range. Specialists did ad-hoc verification checks of each other’s answers, based on their knowledge of the respective plantations and data from ongoing audits and monitoring programs. As the environmental specialists were actively involved in the development and preliminary testing of MATCH, there was no need for additional induction and training workshops. They worked unaccompanied over a period of six weeks (15 April to 30 May 2018). Each management assessment took 45–60 min to complete. The relevant ethical approval was obtained from the Research Ethics Community of Stellenbosch University (project number 0936).

We tested the sensitivity of MATCH by comparing operational outcomes in Zululand with those in the Midlands. These two regions varied greatly in their abiotic environments, socio-economic contexts, and restrictions posed by legal authorities (e.g. Fire Protection Associations). As a result, these regions differ in their respective environmental risk profiles, which, in turn, affect management priorities and operational outcomes. High-risk areas are prioritized for management intervention, after which lower risk areas will be managed when there is time and money left to do so. Therefore, despite similar best management practices for the two regions, differences in their risk profiles act as a filter that determines which management practices are implemented, and which get postponed. MATCH identifies these differences.

2.3. Statistical analyses

Statistical analyses involved a weighted comparison of operational outcomes inside plantations vs. operational outcomes according to Best Operational Practice (BOP). To this end, we calculated the level of compliance for each section in a stepwise procedure. We calculated the 1) level of compliance (C) per question by comparing the answer to each question with BOP. Exact matches scored one, while complete disagreements scored zero. Partial agreements (e.g., ‘Sometimes’ vs. ‘Yes’) scored 0.5. All questions left blank or marked ‘Not applicable’ were omitted from further analyses. Then, we calculated the 2) weighted score per question (CW) by multiplying level of compliance (C) with each question’s assigned weight (W; range 1–4). The sum of all questions’ weighted scores (CW) is equal to the raw score per section (RC). Not all sections had the same numbers of questions. Hence, we 4) divided the raw score per section by the number of questions (NQ) to generate the standardized score per section (ST). In parallel, the standardized BOP score (SBOP) for that section was calculated following the exact same steps, i.e. raw BOP score per section (RBOP)/number of questions per section (NQ). Finally, the standardized score per section (ST) was divided by the standardized BOP score (SBOP) to generate the weighted index of compliance (WIC) per section, which always varied between 0 and 1. We reported on the WIC for each section, as a measure of how well operational outcomes address pressures in the system.

\[
RC = \sum (C * W)
\]
\[ \text{ST} = \frac{\text{RC}}{\text{NQ}} \]  
\[ \text{RBOP} = \sum (\text{BOP} \times W) \]  
\[ \text{SBOP} = \frac{\text{RBOP}}{\text{NQ}} \]  
\[ \text{WIC} = \frac{\text{ST}}{\text{SBOP}} \]  

Next, we were interested in knowing which operational outcomes showed 1) full compliance with BOP across all plantations, 2) large-scale non-compliance among plantations, and 3) regional differences in compliance. Therefore, we calculated the average level of compliance (=C) for each question, i.e. the sum of C for all relevant plantations/number of relevant plantations. Focusing on relevant plantations means a plantation without, for example, livestock grazing, would be excluded from the grazing calculation. Questions with an average C > 0.95 (i.e. full compliance), and C < 0.30 (i.e. non-compliance) were identified and briefly discussed. To identify questions exhibiting a strong regional response, we calculated the average C per region. Then, we selected all questions where the absolute value of the difference between regions was >0.3, i.e. |average C for Midlands| minus |average C for Zululand| > 0.3. Central themes of such cases were also briefly discussed.

3. Results

3.1. Themes of full compliance and non-compliance

We identified 57 questions for which there was full compliance (average level of compliance (C) > 0.95) with BOP, and 23 questions for which there was large-scale non-compliance (average C < 0.30) (Appendix 3). All issues identified concurred with findings from data-intensive audits and monitoring programs.

For the fire regime, questions with full compliance involved planning at different spatial scales, the integration of ecological burning requirements into plans, and the practical execution of plans (e.g. patch burning mosaics). Concerns of non-compliance were around lack of integration between fire protection and soil conservation (e.g. use of hoeing as firebreak preparation method) (Appendix 3).

There was no control over domestic livestock grazing, as was evident from non-compliant matters that prevailed at every step in the livestock management system (Appendix 3). These included issuing of grazing permits, monitoring and record keeping, non-compliance with recommended stocking rates, and lack of enforcement of good grazing practices (e.g. rotational grazing and full-season rest).

For control of invasive alien plants (IAPs), planning reflected different spatial scales (i.e. compartment vs. plantation) and time frames (short vs. long-term). Monitoring of IAP species was detailed, records were up to date, and there was good capacity to identify new and emerging species (Appendix 3). IAP treatments (e.g. type of herbicides, and age appropriate application methods) were well executed, which resulted in excellent kill rates (i.e. effectiveness of operations). Prioritization of IAP control considered financial costs of clearing as well as ecological considerations (e.g. known localities of threatened and protected species). The only concern was the lack of integration between annual and longer-term plans for most plantations. Nevertheless, 57% of plantations showed a decline in total IAP cover. All plantations with declining IAP trends achieved their Annual Plan of Operations (APOs) and showed a decline in proportion of mature IAPs in follow-up compartments, whereas all plantations without declining IAP trends did not achieve their APOs and did not show progress in follow-up commercial timber or conservation compartments.

Width of wetland and stream buffer zones was fully compliant with national delineation guidelines, and these zones (and high-risk peatlands) were indicated on relevant maps (Appendix 3). Wetland and stream buffers did not suffer damage from timber harvesting operations, and there were also no other issues of large-scale non-compliance with BOP for wetland and stream buffers, or high-risk peatlands.

Soil erosion from roads and borrow pits were well-managed (Appendix 3). The only concern was point erosion associated with some roads. For timber compartments, planning which had environmental constraints (e.g. steep slopes and erodible soils) for harvesting and silvicultural activities, were integrated into operations (e.g. choice of machinery or slash management method). Good monitoring programs were in place, and mitigation measures were implemented wherever harvesting or silvicultural activities caused damage to the environment.

Issues of non-compliance with BOP resulting from technological changes, i.e. from manual labor to mechanized harvesting and modernized silvicultural establishment practices (i.e. pitting, planting, and weed control).

For environmental incidents, there were detailed and up-to-date records, and corrective actions were implemented within specified time frames (Appendix 3). There were no matters of large-scale non-compliance for environmental incidents.

3.2. Weighted index of compliance (WIC) per section

Overall, there was considerable variation in the weighted index of compliance (WIC) for pressures considered in timber production landscapes (Fig. 2). Management of livestock grazing was by far the worst performer (mean WIC ± SE: 0.48 ± 0.03), but it was also the only exogenous pressure in the system. This was followed by fire management (0.69 ± 0.01). However, there was good management (WIC > 0.75) of all other endogenous pressures in the system (Table 2). Management of wetlands and stream buffers was very good (0.90 ± 0.02), and indicators of degradation in these buffers appear to be largely under control.

Compliance with BOP in Zululand was similar or greater than in the Midlands for all sections, except environmental incidents (Fig. 2). For this section, Zululand still needs to improve its reporting of major incidents within specified time periods, investigations of incidents within specified time periods, and implementation of corrective actions that address the cause (and not just the consequence) of the incidents that originate within the system boundary.

3.3. Regional responses in management

There was a total of 63 questions with regional responses, i.e. where the average level of compliance (=C) per question differed by > 0.3 between regions (Appendix 4). For fire management, the specific questions exhibiting such a regional response involved detail in the fire plan, fire records, and different firebreak preparation methods. Most importantly, however, is that plantations in the KZN Midlands generally
term targets. Nevertheless, there was a need for greater integration of
reasons for lower compliance with BOP in the Midlands were lack of
plantations where their annual plans and longer-term IAP control plans
stump applications) in Zululand to further curb financial costs. The
regional differences that could influence the longer-term trajectory of
treated species or trajectories of total IAP cover, but there were a few
stock damage to newly planted timber saplings in the Midlands, but not
managed in the Midlands. Grazing permits were issued according to
recommended stocking rates, livestock numbers were routinely moni-
tored, livestock were kept within their designated areas, and offspring
achieved their targets (measured in hectares) for burning conservation
corridors of fire-dependent grassland and savanna (Appendix 4). Plant-
tations in Zululand generally did not achieve these targets, largely due to
insufficient labor and the short window allowed by Fire Protection As-
associations (FPAs) for safe burning.

Similarly, we considered the specific grazing questions with a
regional response. Livestock grazing was more prevalent in Zululand
plantations, i.e. only two Zululand plantations contained within iSi-
mangaliso Wetland Park were without livestock grazing. This contrasts
with the Midlands where ~38% of conservation areas were without
livestock grazing. Furthermore, some habitat types (e.g. forests) in
conservation corridors of both regions were ungrazed. Cattle was the
most common type of livestock in both regions. However, livestock
owners were better organized, and livestock records were more com-
plete for plantations in Zululand than in the Midlands (Appendix 4). An
important regional difference was the existence of working relationships
between foresters and livestock associations for all Zululand plantations,
but for only 60% of plantations with livestock grazing in the Midlands.
This relationship of trust was identified by assessors as an enabling
mechanism for gaining control of livestock grazing, because it provides
the backbone of compliance with grazing permit conditions. In contrast
to Zululand, there was a stronger systematic approach to grazing man-
agement in the Midlands. Grazing permits were issued according to
recommended stocking rates, livestock numbers were routinely moni-
tored, livestock were kept within their designated areas, and offspring
were sold off (Appendix 4). A major contravention with BOP was live-
stock damage to newly planted timber saplings in the Midlands, but not
in Zululand.

The IAP section showed no difference between regions for kill rate of
treated species or trajectories of total IAP cover, but there were a few
regional differences that could influence the longer-term trajectory of
IAP control in plantations. Zululand plantations showed greater
achievement of annual targets, greater decline of mature plants in
follow-up compartments, and greater capacity to respond to new and
emerging IAP species (Appendix 4). Also, in Zululand, there were a few
plantations where their annual plans and longer-term IAP control plans
aligned, which had a measurable effect towards achievement of longer-
term targets. Nevertheless, there was a need for greater integration of
fire with existing IAP control methods (e.g. foliar spraying and cut-
stump applications) in Zululand to further curb financial costs. The
reasons for lower compliance with BOP in the Midlands were lack of
labor, terrain impediments that restricted access to teams without
specialized training, and propagule spill-over from commercial
compartments and neighboring land into conservation corridors.

For soil conservation inside timber compartments, regional differ-
ences mainly concerned silvicultural activities. Slash treatment alter-
 natives to burning were employed on the nutrient-poor alluvial sands of
Zululand, but less often in the Midlands (Appendix 4). Furthermore,
planning of silvicultural activities reflected environmental constraints
(e.g. steep slopes and sensitive soils).

4. Discussion

The prevailing narrative in socio-ecological systems is one of
anthropogenic activities affecting the state of the environment (Ripple
et al., 2017; Sánchez-Bayo and Wyckhuys, 2019). A complementary
view is that a changing environment will impact human quality of life
(World Economic Forum, 2019). The neglected narrative is that people
mitigate the negative impact of anthropogenic activities on natural
ecosystems with effective management (e.g. Keesstra et al., 2016). As
result, there is a lack of indicators that assess management effectiveness
at the operational level (Cornier and Elliott, 2017), which leaves a gap
in our knowledge of anthropogenic change (and change reversal) in
socio-ecological systems (Niemeyer and de Groot, 2008).

In response, we successfully developed a new, sensitive and practical
monitoring tool of management operations in commercial forestry
plantations, South Africa. This is the first tool to simultaneously consider
management operations of all major pressures in a production system.
Following our initial objectives, we identified the management re-
 sponses, as captured by the point-form questions and statements that
formed the building blocks of MATCH. Then, we trialed a Google-based
user interface, with which we identified management gaps in current
operations of selected forestry plantations. The detail at operational
level allowed us to translate these gaps into progress made (using WIC
scores) towards management objectives, which need to be achieved to
reach strategic goals of sustainability. The final objective, to discuss
legal drivers and practical constraints to effective management, ensues
below. Overall, MATCH has value to on-the-ground foresters interested
in self-discovery of non-compliant matters, and it has value to decision-
makers in higher structures of an organization as it provides transparent
measures of progress.

4.1. Soil conservation

We found soil erosion from roads and timber compartments to be
well-managed. This pressure has a clear management objective (i.e. ‘stop it’) to steer operations. Moreover, soil erosion is concentrated into
definite spatial effects. For example, in commercial timber compart-
ments, pressures (e.g. hot slash burns) changes the on-site soil envi-
ronment (e.g. soil exposure), which require on-site monitoring and
management actions (e.g. erosion control measures) to mitigate the
impact to society, in this case, timber yields. Effects are direct and
measurable at the scale of operations. Moreover, there are good records
available, which probably strengthened the feedback loop (i.e. planning →
implementation of plans → assess effectiveness → adaptation →
planning) in the adaptive management cycle.

4.2.1. Practical insights into fire management

Unlike soil conservation, the fire management objective is a nuanced
balance between fire risk management and conservation burning. Commer-
 ally, fuel load reduction is a major management objective, because it simplifies
protection, prevention, and suppression of unplanned wildfires in plantations (DAFF, 2015). Ecologically, rotational
burning in a patch mosaic configuration and at intermediate frequencies
(i.e. 2-3 years) would be best for grassland biodiversity (SANBI, 2014).
These objectives are not mutually exclusive, but they are often managed
by demarcating different parts of the corridor network to fire protection
and conservation burns, respectively. This dichotomous approach is a

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**Table 2**

|                          | All plantations | Midlands | Zululand |
|--------------------------|-----------------|----------|----------|
| Fire management          | 0.69 ± 0.01     | 0.70 ± 0.02 | 0.69 ± 0.02 |
| Livestock grazing        | 0.48 ± 0.03     | 0.42 ± 0.08 | 0.52 ± 0.01 |
| Control of alien plants  | 0.78 ± 0.02     | 0.75 ± 0.04 | 0.81 ± 0.01 |
| Wetland and stream buffers| 0.90 ± 0.02   | 0.86 ± 0.03 | 0.94 ± 0.02 |
| Special case: Peatlands  | 0.90 ± 0.10     | –         | 0.90 ± 0.10 |
| Soil erosion from roads  | 0.78 ± 0.03     | 0.72 ± 0.03 | 0.83 ± 0.04 |
| Special case: Borrow pits| 0.79 ± 0.05     | 0.81 ± 0.06 | 0.71 ± 0.04 |
| Soil erosion from timber compartments | 0.82 ± 0.02 | 0.77 ± 0.00 | 0.87 ± 0.01 |
| Environmental incidents  | 0.96 ± 0.02     | 1.00 ± 0.00 | 0.91 ± 0.03 |
problem, because the effects space for fire management is not just at the patch level (like soil erosion) (de Ronde et al., 1990), or measurable only in the short-term.

There are numerous interactions between fire management, corridor design, and fuel load properties that manifest over time at the landscape level. For example, forestry plantations have many narrow corridors, in part due to compliance with the national wetland delineation program (discussed below). Burning of narrow corridors presents a fire risk to adjacent timber compartments. To mitigate the immediate fire risk, narrow corridors are not burned at recommended frequencies, which causes them to become encroached with indigenous bush. Fire exclusion, moisture limitations, and grazing are important local drivers of bush encroachment, while atmospheric CO₂ is an important one at global scales (e.g. Wigley et al., 2010). In corridors, this bush-encroached state is an intermediate successional stage between grassland and indigenous forest, and has very little biodiversity value (Gaigher et al., 2019). If left unburned, it usually develops into indigenous forest. However, narrow corridors are trapped in this bushy state, because they are typically burned with adjacent timber compartments at the end of each harvesting cycle (i.e. 7-10 years). It might be tempting to view this as just an ecological problem, but we argue that bush encroachment increases the long-term fire risk for commercial timber production at the landscape scale. This is because fire risk is an emergent property measured at the landscape level (Sande Silva et al., 2010).

Apart from correct placement and preparation of firebreaks, training of staff, equipment maintenance, early detection and response time, and ecological properties of grassland and indigenous forest in the rest of the landscape (i.e. outside firebreaks) are all helping to control runaway fires. In contrast, the intermediate successional stage of bush has predominantly woody fuel that burns much hotter than grassland (DAFF, 2016). Moreover, bushy areas do not have the moist microclimate of indigenous forest patches that convey fire protection properties to the landscape. Nor are they spatially restricted to steep gorges, outside natural fire paths created and maintained by prevailing winds (Geldenhuys, 1994). Thus, there are no natural processes that prevent bushy areas from burning when there is a runaway fire. Moreover, when they burn, they burn hot. This means that fire exclusion from narrow corridors (to mitigate an immediate fire risk at the time) can have the unintended long-term consequence of increasing the fire risk profile of the whole plantation. This renders bush encroachment in narrow corridors as not only an ecological problem, but also an economic concern. It is necessary to consider the larger landscape, and consider long-term future trajectories to fully account for the cost of current practices, offset against long-term savings, when making everyday management decisions (Allen and Gunderson, 2011; Peterson et al., 2003).

### 4.2.2. Legal drivers of fire management

We already established that fire is used in conservation corridors, as well as in commercial timber compartments, and for different purposes: ecological burning, risk management and modernized silvicultural establishment practices (i.e. pitting, planting and weed control). All burning inside conservation corridors and commercial timber compartments fall under the National Veld and Forest Fire Act (Act 101 of 1998), which means adhering to the fire season published annually by the regional Fire Protection Associations. However, it is possible to burn grassland corridors under the Conservation of Agricultural Resources Act (CARA, Act 43 of 1983) after the fire season has closed. Due to fire risk and how legislation is structured, firebreaks and slash burns are prioritized, and conservation burns only occur once the other two are done. However, foresters face additional risks when they burn under CARA outside the fire season, and some are not prepared to face the risks or consequences of a controlled burn getting out of hand. Even if foresters have the necessary experience and resources to risk burning outside the fire season, winter rains in Zululand (with its subtropical climate and mild winters) might cause greening of the receiving

environment. When there is already only a short safe burning window, this combination of factors cause conservation burning targets not to be achieved, and fire not to be effectively used in IAP control. This is also why foresters in this region explored slash management alternatives to burning.

### 4.3. Protection of water resources

The effect of legislation on management may be enforced through licenses, as can be seen in the protection and management of freshwater ecosystems. A major goal of the National Water Act (Act 36 of 1998) is to safeguard water security in the country (RSA, 1998). In accordance with this act, commercial forestry is a stream-flow reduction activity that requires a water use license (DWAF, 1999). These license conditions enforce control of IAPs and compliance with the national wetland delineation guidelines (DWAF, 2005, 2008). Wetland delineation is an expensive operation with far-reaching consequences for ecological state, management requirements, corridor design, and road infrastructure development. The removal of timber compartments from wetland and stream buffers creates narrow corridors, with a flush of alien plants that require intensive management, including regular burning that has its own suite of problems (outlined above). Moreover, valley bottom cut-off roads are constructed to mark the new boundary between wetlands and timber compartments, as well as to simplify management inside newly-created wetland corridors. Wetland delineation was completed in all plantations, and timber compartments were consistently withdrawn >20 m from temporary wetland edges, but IAPs in wetland and stream buffers still exceeded acceptable levels in some plantations. The interaction between corridor width and burning probably contributed to this problem.

### 4.4. Control of invasive alien plants (IAPs)

While water use licenses enforce invasive alien plant (IAP) control in plantations for the purpose of water security, the National Environmental Management: Biodiversity Act (Act 10 of 2004) regulates control of IAPs for the purpose of ‘preventing or minimizing harm to habitats, ecosystems and the environment’ (DEA, 2004, 2014). In compliance with both legislative frameworks, the forestry company involved in this study employed a systematic and data-based approach to IAP management. They had an annual IAP monitoring program with independent third party auditors that provided up to date records of all listed IAP species, their cover abundances, maturity levels and occurrence patterns (scattered vs. clumped) for all conservation corridors in all plantations. It is only a legal requirement of organs of state (e.g. Protected Areas) to have such detailed IAP records (DEA, 2004), although there are concerns around data precision of such assessments (Cheney et al., 2018). Reportable measures for the forestry company were trends in total IAP cover (at patch and plantation scale), proportion of mature plants in follow-up compartments, and kill rate of treated species.

Through adaptive management (Foxcroft and McGeech, 2011), the forestry company learned to identify spatial prioritization strategies and treatment combinations that were most cost-effective, resulted in the best kill rates, and led to overall declines in IAP cover. Interestingly, their spatial prioritization strategy was to focus on areas with low IAP infestation levels, follow-up areas, and ecologically-important areas (e. g. wetland and stream buffers, and areas with threatened or protected species). More densely infested areas were only added to the IAP treatment plan when the above operational outcomes were fulfilled, and there was sufficient resources available for initial and follow-up treatments until IAP cover was reduced to maintenance levels (0-5% cover). This systematic and data-based approach led to year-on-year declines in IAP cover for 57% of plantations included in this study. This was at least as good (van Wilgen et al., 2017), or better than for projects run by the national alien plant control program (Kraaj et al., 2017; van Wilgen et al., 2012). It was only in plantations where annual plans were not
fully implemented where declines in IAP cover were not achieved. Hence, the IAP control plans were effective, and resources should be made available to continue operations according to these plans.

4.5. Uncontrolled livestock grazing

In direct contrast with IAP control, livestock grazing was very poorly managed. This was due to a severe breakdown in the management loop from recommended stocking rates → grazing permits, monitoring and record keeping → enforcement of good grazing practices in accordance with national guidelines (SANBI, 2014). According to the current system, the forester should issue permits to community livestock owners, and maintain a record of livestock owners, their allocated number of livestock, and their allocated grazing concessions. Compliance with permit conditions should then regulate grazing inside plantations. However, permits were not aligned with stocking rates recommended by rangeland specialists, and the provincial bioresource groups (Bioresource Programme, 2009), or in accordance with the Conservation of Agricultural Resources Act (Act 43 of 1983). Moreover, there was very little monitoring of livestock numbers due to lack of human resources, and records were mostly out of date, which means there was no basis for enforcement. Even if there was a basis for enforcements, there were no consequences for illegal grazing. This led to large-scale uncontrolled grazing, which impacted most grassland corridors in Zululand and the Midlands.

Uncontrolled grazing increases the risk of overgrazing, which caused severe environmental degradation in former homelands in South Africa (Hoffman and Todd, 2000). However, it is not synonymous with overgrazing. Moreover, as with fire, there are interactions between this disturbance and ecological characteristic of the landscape. Livestock prefer palatable grasses, but many delineated wetland corridors in Zululand are dominated by unpalatable grass species (Joubert et al., 2016). Moreover, domestic cattle generally avoid steep and rocky slopes, indigenous forests, and bush encroached corridors. Where these ecological filters are abundant (Crous et al., 2013), the risk of overgrazing and associated impacts will be lower. It might be lowered even further where there is grazing land available outside the plantation boundary. This emphasizes the importance of considering local context when formulating potential solutions to the problem of uncontrolled grazing.

Importantly, the current forestry-livestock grazing model has forestry companies carrying all the costs of grazing (i.e. sheet erosion, biological invasions, and damage to trees), while livestock owners only extract benefits. Hence, there is no incentive for livestock owners to voluntarily change their damaging ways.

There must be consequences for non-compliances with grazing permit conditions to change the current state of affairs, as punishment and reward combine to shape human behavior (Kubanek et al., 2015; Wachter et al., 2009). Another consideration is the role of cattle in African culture, i.e. they are not sold off for economic gain but kept as a status symbol. This means that if we stay on the current trajectory, cattle numbers, grazing pressure and ecological losses will continue to increase, and forestry companies will bear the costs of those losses. This needs to change urgently to reflect a more equitable sharing of costs and benefits between landowners and livestock owners, and to enforce trade of cattle in the open market system. There is a non-profit organization ‘Meat Naturally’ with a model that works well in rural areas (https://www.meatnaturallyafrica.com/), but alternative options might have to be explored in more urbanized or industrialized contexts. Changing and overcoming inertia in the current forestry-livestock grazing system will require substantial investments on multiple fronts. The current system cannot be changed by only addressing the consequences, as is the norm for managing exogenous pressures. It needs to be addressed at root cause level, and this will require shifting the boundaries of the socio-ecological system to include other stakeholders (e.g. community members and other private landowners with the same problem) in the larger landscape. Forestry companies have yet to find a grazing model that yields effective control over livestock grazing. Learning from one another’s successes and failures is important.

4.6. Prioritizing management action

Prioritization of management efforts underpins management decisions, while these decisions precipitate in management responses captured in MATCH. Prioritization of environmental management considers specific actions (i.e. what to do), a sense of urgency (i.e. when to do it) and a spatial element (i.e. where to focus). Of these, only spatial prioritization is a well-established discipline in conservation (e.g. Margules and Pressey, 2000), which necessitates learning from other disciplines.

In project risk management, prioritization of management actions for implementation within specified time frames is generally based upon measures of probability and impact, when risks are realized. Where managers are uncertain about measures of probability, best available data and best available expertise are combined to overcome pure data limitations (Chapman, 2006). Once probabilities are established, risk factors (or pressures) are prioritized according to the nature of impact. Hence, resources would be steered towards impacts that result in permanent losses that cannot be restored, losses happening now, and losses of scarce and valuable resources. Moreover, management would focus on emerging rather than established impacts, impacts that can spread rapidly, if left unmanaged in the short-term, and impacts that are acute and spatially restricted. In practice, this means that an active erosion gulley would be prioritized over a stable erosion gulley, and soil loss occurring now would be prioritized over biological invasions that would cause losses in future. However, following this approach also means that the widespread and chronic impacts associated with poor burning and grazing practices (e.g. sheet erosion) would not emerge as a management priority. We need more than likelihood and impact to prioritize management actions.

There is a clear distinction in project risk management (and other disciplines) between the source of a risk and its impact (Chapman, 2006). Its relevance to our case is that management can proactively prevent damage by focusing on the source of impact (e.g. unprotected drain outlets along a gravel road), or it can reactively (and repeatedly) repair damage to that road (Cormier et al., 2019), with the latter being the more expensive option in the long-term. A useful guideline is to use the proactive approach for risk factors with known sources (i.e. unprotected road drains), known probabilities (i.e. when it rains) and/or known impacts (i.e. damage to roads), and this approach should also consider trade-offs between different management alternatives to best achieve the goal of preventing economic and ecological losses. This leaves the more expensive reactive approach for addressing impacts arising from uncertain events, such as extreme weather or catastrophic fires.

These prioritization strategies assume that someone took ownership of the problem, and that effective management options exist to address the problem. If either one of these assumptions are not met, the associated problems will persist. To decide whether a persistent problem should be escalated to senior management, Chapman (2006) suggested a traffic light approach. ‘If an issue has clear and acknowledged ownership plus plausible responses, give it a green light. If an issue has clear and acknowledged ownership but no plausible responses as yet, give it an amber light. Otherwise give it a red light. Focus senior management attention on the red lights first.’ Ownership of problems is simple when there is a concentrated effects space, as discussed earlier for protection of soils. However, designation of ownership becomes progressively more complicated when operating across institutional boundaries, for example, when there are multiple actors (some from outside the organization), when the source of risk does not coincide with site of impact, and when the impact influences a scarce resource for which there is a high societal demand, as was the case for water in the uMhlathuze river catchment. Legal action like wetland delineation, or voluntary strategies
can address these transboundary issues. For the uMhlathuze catchment, a voluntary partnership between government, strategic role-players from industry (including forestry), and civil society partners was formed to address water security (https://wateractionhub.org/projects/1098/d/umhlathuze-water-stewardship-partnership-uwasp/).

There is not a one-size-fits-all strategy that will effectively address all risk factors, and certainly not those transcending disciplinary and organizational boundaries in the socio-ecological system. It is the combination of different prioritization and management strategies, with strengths derived from each, and fluidity to adapt to change, that will yield effective control of pressures in the landscape.

4.7. Recommendations for environmental management

Adaptive management is key to the sustainability of socio-ecological systems, and monitoring and accurate record-keeping is key to learning, i.e. the mechanism for adaptation. Especially for livestock grazing, there needs to be an accurate record of the strengths and weaknesses of different approaches, and how these lead to successes and failures in gaining control of the grazing problem. Until livestock grazing is brought under control, a moratorium needs to be placed on grazing of all ecologically sensitive areas. These no-go areas need to be strictly protected.

Control of IAPs and soil erosion are far advanced, and the correct structures are in place to facilitate learning and adaptation, where needed. These structures should be maintained so that they continue to yield the relevant types of data needed to respond to changes in the system.

In this study, fire management integrated short-term risk and the burning requirements of fire-dependent vegetation types very well. However, the current fire management regime failed to balance short-term costs and risks (of patch burning) against longer-term savings of having a well-managed landscape with ecological properties for controlling runaway fires. This should become a research focus, as we still do not adequately understand how to balance different objectives (fuel load reduction vs. ecological burning) and different economic measures (risks, costs, and savings) over different temporal scales (where there is a time lag in response) and with effects of patch management manifesting at the landscape spatial scale.

4.8. Roll-out of MATCH for wider implementation

MATCH was developed as a working and living monitoring protocol, where repeated use leads to correction of operations, and consequent adaptations of the monitoring protocol. The first round of assessments already led to some changes (Appendix 5). As other role-players in the forestry industry start using it, more changes (e.g. in level of detail) will probably follow, and these are good, because monitoring protocols need to stay in step with the data requirements of a dynamic socio-ecological system.

Training workshops are recommended, where assessors demonstrate how to answer questions and ensure consistency. Only then will results be comparable among different plantations. Moreover, skilled facilitators should stimulate discussion (and debate, if necessary) of management issues to facilitate peer-to-peer learning, especially between young and experienced foresters within an organization.

MATCH was not developed to stand in isolation, but rather to fit in with existing structures and to draw different data streams into a single space. This means that answers in MATCH are supported by actual data, but it also implies that statements about management effectiveness (e.g. IAP control) are only as reliable as the underlying quality of data. Its data dependency means that MATCH can also be used to identify knowledge gaps, i.e. what is known and what information is still required to make informed management decisions. This is in addition to the original purposes, i.e. to identify management gaps in existing operations, and to use these to report progress towards strategic goals.

Where MATCH gets used to bridge the management divide from on-the-ground managers to strategic decision-makers, the underlying data streams would need to be verified. An integrated data management system, graphically displayed on a dashboard can help manage these data streams, for easy access and verification.

MATCH is not a prioritization tool, as it does not tell you where to spend your money. Just because there is a management gap does not imply that it is best for overall efficiency of the management system to fix that specific problem. Trade-offs exist in the resource constrained reality of environmental management, i.e. allocating resources to fix one problem might imply that another problem goes unmanaged. These trade-offs need to be carefully considered in a prioritization process that accounts for risk (or probability), impact (e.g. intensity or permanency of losses), and different sources of uncertainty (notably ownership and existence of viable management solutions) when making decisions about where to focus, and what to do at that focus point. Knowing what to do, when and where to do it, and completing individual tasks with excellence enables efficiency in the management system.

This is the first monitoring tool of its kind, and we propose that there is sufficient evidence here to show that the protocol has potential to be adapted for other industries too. While the question content would have to be rewritten, the steps followed to develop MATCH still remain applicable, i.e. define the system boundary, identify all major environmental pressures, summarize management responses into point-form questions, compare answers for each question to BOP, weight answers, and calculate and report management efficiency for each pressure. For example, this protocol was used to develop EQ4CO – a management tool that ensures compliance with BOP for all safety protocols that need to be in place for workers sharing common work spaces during the COVID-19 outbreak. This tool is freely available for any organization to use in their COVID response (URL: https://arcg.is/aDLbr). In addition, although not demonstrated explicitly here, design of these tools may follow risk assessments put in place to uphold ISO or certification standards around occupational health and safety, social matters, and the natural environment. This allows for a streamlined assessment of management responses, tailored to key risk pathways relevant to specific industries and their local contexts. Throughout, the aim should be to develop tools that provide integrated, consistent, transparent and simple measures of progress. This facilitates easy communication of issues among different managerial hierarchies in an organization, so that an integrated response can be formulated and rapidly implemented to improve management quality and stop environmental degradation.

5. Conclusion

Effective management is necessary to mitigate negative anthropogenic effects on ecosystem state. This is also true for commercial timber production landscape. We developed a management monitoring protocol (Management Check: MATCH) that assesses how well management operations address major pressures at the operational level. Upon testing the protocol, we found a high degree of integration between national legislation and on-the-ground environmental management, and this influenced how well specific endogenous pressures (e.g. IAPs) in specific ecosystems (e.g. wetland and stream buffers) were managed. We also identified constraints to fire management, and discussed how management actions can be prioritized to further improve efficiency of the management system. MATCH effectively converged data streams from different sources into a single space, for an improved understanding of the dynamics management system. It has great potential for wider use in commercial forestry as well as other industries.

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Apart from funding, the NRF did not influence this study. However, this project was a collaboration between academia, independent ecologists, and a major forestry company (Mondi). Mondi employees were instrumental in shaping various aspects of this study. These are outlined in ‘Declaration of interest’.

Declaration of competing interest

The authors declare that the following collaboration and financial interest, which might be considered as potential competing interests. The research was financially supported by Mondi Group through the Mondi Ecological Network Programme (MENP) based at the Department of Conservation Ecology and Entomology, Stellenbosch University.

Furthermore, this project was the result of collaboration between a university research group, independent ecologists, and Mondi South Africa. The research objective (i.e. to develop a monitoring protocol focusing on management outcomes at operational level) was suggested by R. Lechmere-Oertel, with support from V. Ross-Gillespie and D. Walters at a workshop organized by B. Corcoran (environmental manager for Mondi South Africa). Consequently, L. Joubert-van der Merwe developed the content of sections in the monitoring tool, with valuable input provided by L. Shaw and P. Belebese (both Mondi-employed environmental specialists). L. Joubert-van der Merwe also had access to some of Mondi’s procedures, norms and standards. The ‘review of content’ phase of the project was led by B. Corcoran and M. Sikhakhane (Mondi environmental specialist). The ‘testing’ phase of the project had the help of her co-authors. L. Shaw offered practical insights regarding forest certification schemes and legislation, which were incorporated into the paper. L. Shaw only influenced key messages in one section of the paper, entitled: ‘Roll-out of MATCH for wider implementation’. Separate from the MATCH project, the corresponding author and M. Wilson (Senior GIS Specialist at Mondi South Africa) used the principles developed in this paper to build the EQ4CO tool, which was mentioned in ‘Roll-out of MATCH for wider implementation’.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jenvman.2020.110922.
