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Understanding the effectiveness of policy instruments to encourage adoption of farming practices to improve water quality for the Great Barrier Reef

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ABSTRACT

Governments in Australia and internationally are experimenting with policy instruments to facilitate the adoption of farming practices with reduced environmental impacts. The Great Barrier Reef (Australia) is one such case, where sustained efforts over 20 years have yielded insufficient progress towards targets to reduce the impacts of agriculture on water quality in downstream marine ecosystems.

We present a critical review of policy instruments as implemented in Great Barrier Reef catchments. We catalogue the evolving mix of policy instruments employed in reef programs, and examine evidence of the effectiveness of agricultural extension, financial incentives, and direct regulation of farming practices. There is little robust evidence to assess instrument effectiveness, in part due to the evolving mix of the instruments employed, weak program evaluation and heterogeneity of agricultural enterprises. We identify the need to improve the understanding of instrument fit to landholders and enterprises. We recommend a modelling approach to clarify pathways to impact and guide improved policy evaluation.

1. Introduction

While a major source of global food, agricultural production systems are also a major driver of global environmental degradation, including water extraction, water quality pollution, soil degradation, greenhouse gas emissions, and impacts on biodiversity (Carvalho et al., 2019; German et al., 2017). The failure of agricultural systems to provide public goods such as ecosystem services (including water quality) occurs due to a lack of fully defined and allocated property rights for these goods and services (see Bromley, 1989, 1991; Challen, 2000; Commons, 1924; Schlager and Ostrom, 1992 for a discussion of property rights and market failure). Market failure is frequently exacerbated by other factors such as power imbalances and weak institutions that facilitate rent seeking behaviours. When rights are not well defined and the resulting externalities are under or uncompensated, government intervention, in one form or another, may be justified (Bromley, 1991; Challen, 2000) as long as this is welfare enhancing (Whitten and Bennett, 2005).

Policy instruments are “the techniques through which governments generate, evaluate, and implement policy options” (Capano and Howlett, 2020, p. 1). Policies to reduce the environmental impacts of agriculture draw upon a variety of instrument types, while policy instruments across multiple policy domains (e.g., environment, agriculture, regional development) will influence resource use and management (Blackstock et al., 2020). Broadly, policy instruments used to encourage adoption of more sustainable farming practices include information provision (suasive instruments), financial instruments, and regulation, supported by research and development and monitoring and evaluation (Ronchi et al., 2019). Agricultural extension programs are

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information provision services that have traditionally sought to encourage the adoption of new technologies to improve productivity and profitability (Norton and Alwang, 2020) but are now incorporating sustainability objectives as environmental policies seek to reduce the agricultural footprint] (Pannell and Claassen, 2020). Governments also use grants and subsidies, market-based instruments, and direct regulation (Shortle and Horan, 2013). Policy scholars also recognise indirect procedural instruments that support the implementation of the direct, substantive instruments described above (Howlett, 2019). Instruments may shift from their original design through implementation (Thiel et al., 2015). In practice, many instruments are hybrids (a mix of pure suasive, financial, and regulatory instruments) or rely on other instruments to be effective (Blackstock et al., 2020). The mix of policy instruments evolves over time as policy objectives and political imperatives shift (Bouma et al., 2019).

In Australia, and internationally, policies have failed to address agriculture's environmental footprint, which remains the leading cause of major water quality problems around the world (Alons, 2017; Ribaudo and Shortle, 2019; Shortle et al., in press). While environmental indicators (such as water quality) are used to assess overall policy outcomes, the influence of many other factors limits their relevance as a measure of policy effectiveness (Mickwitz, 2003). For example, Waylen et al. (2019) found that EU policy evaluation focussed on environmental outcomes but not policy effectiveness, and that it was unclear how evaluation informed policy decisions at any level. There are limited methods available to assess the effectiveness of individual policies and policy mixes (Weber et al., 2014). Capano and Howlett et al. (2020) identified the need for more research on policy instruments, including understanding the patterns of instrument use, complex behavioural responses, monitoring and evaluation challenges, and the dynamics of policy implementation.

Policy makers frequently believe that behavioural change will result if the correct balance of positive and negative incentives is applied (e.g, financial support and regulation) (Capano and Howlett, 2019; Howlett et al., 2020). However, adoption responses vary with technology (or practice), population and enterprise characteristics, and the broader context (de Oca Munguia and Llewellyn, 2020; Kuehne et al., 2017; Pannell and Zilberman, 2020). Despite extensive research on the adoption of agricultural practices (see, for e.g., Liu et al., 2018; Prokopy et al., 2019; Ranjan et al., 2019; Wauters and Mathijs, 2014) no simple predictive model of landholder responses to policy instruments has emerged to inform policy design (Pannell and Zilberman, 2020). This is in part due to the heterogenous context in which farming takes place (diverse industries and farming systems) (de Oca Munguia and Llewellyn, 2020), but also due to the complex and unpredictable behavioural responses of individuals and confounding social influences (Strassheim, 2021).

Therefore, there is a need to synthesise existing knowledge about how policy instruments influence farmers' behavioural responses and consider how this is likely to vary across diverse social and geographic contexts. To address this need, an explicitly multi-disciplinary approach is required to undertake a critical review of the mix of policy instruments employed to address diffuse water quality impacts from agricultural systems in the Great Barrier Reef (GBR) catchments of Queensland, Australia. Our case study is Australia's GBR, where governments have invested over $1.1 billion (AUD) over nearly 20 years (Australian Government, 2020) to reduce agricultural water pollution impacting on downstream inshore ecosystems. In the following sections, we review the mix of policy instruments as implemented in the GBR, assess evidence of the impact on water quality and the effectiveness of the main classes of policy instruments (suasive, financial, regulatory, and procedural instruments). We then identify important information gaps, discuss the implications for policy, and propose a way forward for applied research into this problem.

2. Study area

The GBR stretches 2300 km along Australia's north-east coast (Fig. 1) and includes 2900 coral reefs, 1050 islands and 46,000km^2 of sea grass beds (Kroon et al., 2016). The GBR was listed as a World Heritage Area in 1981 for its outstanding universal value (Craik, 1992). It is protected by both state and federal government laws and policies (Jacobs, 2014; McGrath, 2010) and is arguably one of the most significant marine protected areas on the planet (Day and Dobbs, 2013). The GBR supports 64,000 jobs (mostly in tourism) and contributes an estimated $6.4 billion (AUD) per annum to the Australian economy (O'Mahoney et al., 2017).

In recent decades, the health of the GBR has declined sharply due to the cumulative impacts of accelerating climate change and ongoing water quality, fishing, and coastal development pressures (De'ath et al., 2012; Great Barrier Reef Marine Park Authority, 2019). While anthropogenic climate change and associated coral bleaching events are the most significant threat (Hughes et al., 2017), water quality is a critical factor contributing to the loss of resilience in inshore reef ecosystems (Brodie et al., 2019; MacNeil et al., 2019).

Agricultural runoff is the primary source of water quality pollutants (Waterhouse et al., 2017), with water quality modelling identifying the dominant sources as sediment from rangeland grazing lands and nutrients and pesticides from coastal sugarcane lands (Waters et al., 2014). The federal and state governments have set water quality targets to meet water quality objectives in the downstream reef lagoon (Brodie et al., 2017). The water quality risks of different agricultural practices have been described in a series of water quality risk frameworks for the major agricultural industries (for example, see Australia Department of Environment & Queensland Department of Environment and Science, 2013a; Australia Department of Environment & Queensland Department of Environment and Science, 2013b). Water quality risk frameworks and spatial modelling are used to prioritise policy interventions and investments at the broad scale (regional, industry) and within programs (on-farm projects). Annual report cards track practice changes (adoption of more sustainable farming practices) that occur through water quality programs, and modelling is used to estimate the water quality benefits (State of Queensland and Commonwealth of Australia, 2020a).

The current mix of policy instruments for the GBR includes a variety of agricultural extension approaches, financial incentives, direct regulation, bilateral planning (federal and state governments) and collaborative governance. Despite significant and sustained investment in multiple policy instruments over the last 20 years, efforts to improve water quality through accelerated adoption of improved agricultural practices have yielded insufficient progress (Waterhouse et al., 2017). For example, the most recently reported results (State of Queensland and Commonwealth of Australia, 2020b) show 13% of sugarcane land and 36% of grazing land have adopted some improved practices (both against 2025 targets of 90% adoption).

Finding effective policy responses to diffuse agricultural pollution is a global challenge. The experience of Australian policy makers is mirrored in water resource management in Europe and the US (Eberhard et al., 2017) including California (Duttterer and Margerum, 2014; Ulibari and Escobedo Garcia, 2020), Florida (Dengler, 2007; Heikkila and Gerlak, 2016), Louisiana (Pathak et al., 2021), France (Bréthaut and Pflieger, 2015; Guerrin et al., 2014), and the UK (Blackstock et al., 2020). While some countries (e.g., China, Denmark) have demonstrated water quality improvements, this has generally involved sustained political commitment, instrument mixes that include regulation, or as a result of severe economic decline (Kroon et al., 2014).

The GBR is an informative case study in the management of diffuse water quality pollution from agriculture due to sustained bilateral investment, targeted prioritisation (of locations and practices), and the use of diverse policy instruments across multiple agricultural industries at a large scale. There is a clear need to synthesise existing knowledge about how policy instruments influence farmers' behavioural responses and

Fig. 1. Australia's Great Barrier Reef and adjacent catchments (source: Eberhard, 2018, p. 126).

consider how this is likely to vary across diverse social and geographic contexts. To address this need, we use an explicitly multi-disciplinary approach to undertake a critical review of the mix of policy instruments as implemented to address diffuse water quality impacts.

3. Methods

We applied a critical realist evaluative lens (Pawson and Tilley, 1997) to the GBR case study. Our analysis was supported by theoretical understanding and clarified with available evidence from the case study setting. Critical realist approaches have been adopted by public health and social sciences to explain complex behavioural responses (Kiss et al., 2020). Realist evaluations examine the validity of assumptions behind program theories to understand what works for who, when, and why (Pawson, 2006). Mechanisms are the pathways through which resources (in this case, policy instruments) affect changes in reasoning (farmer decision-making) in a specific context (GBR farmers) that results in an outcome (adoption of land management practices) (Dalkin et al., 2015).

The application of a critical realist approach in the GBR involved a focus on policy instruments as implemented, a theoretically-informed explanation of pathways of impact, and an expectation that behavioural responses are emergent rather than predictable in a linear sense (Guenther et al., 2020; Michie et al., 2018; Willis, 2012). Consistent with a realist framing (Capano, 2020; Hasle et al., 2014), we conceptualised the research problem as the influence of policy instruments (suasive, financial, regulatory, and procedural) on the adoption of agricultural practices through mechanisms of behaviour change (changes in resources or reasoning of the target audience) (Fig. 2). The diversity of individuals, enterprises, and practices are strong determinants of whether the instruments trigger mechanisms of behaviour change, and the broader context (including social, market, climate, and political forces) are also important. We examined not just evidence of effectiveness, but causal explanations of the behavioural responses to policy instruments that encourage the adoption of improved agricultural practices.

The analysis of policy instruments must therefore reconcile the theoretical understanding of how different instruments achieve change with the messy realities of policy instrument selection and implementation and the complexities of behavioural responses in diverse target populations. Policy analysts recommend closer attention to the mechanisms through which policy instruments influence behaviour to understand the effectiveness of individual instruments, and ultimately, the impact of policy mixes (Capano and Howlett, 2020; Dunlop and Radaelli, 2020; Weber et al., 2014).

We conducted a critical review of the literature to assess evidence of the effectiveness and impact of policy instruments employed for a specific environmental policy challenge: to improve agricultural water quality in Australia's Great Barrier Reef catchments. We adopted the definitions of effectiveness and impact used by the Queensland Reef Water Quality Program (Roberts et al., 2018b). *Effectiveness* is defined as how well the instrument is delivering outputs that relate to program objectives (adoption of improved practices) and *impact* is the measurable effect of the whole program (suite of policy instruments) (Roberts et al., 2018b).

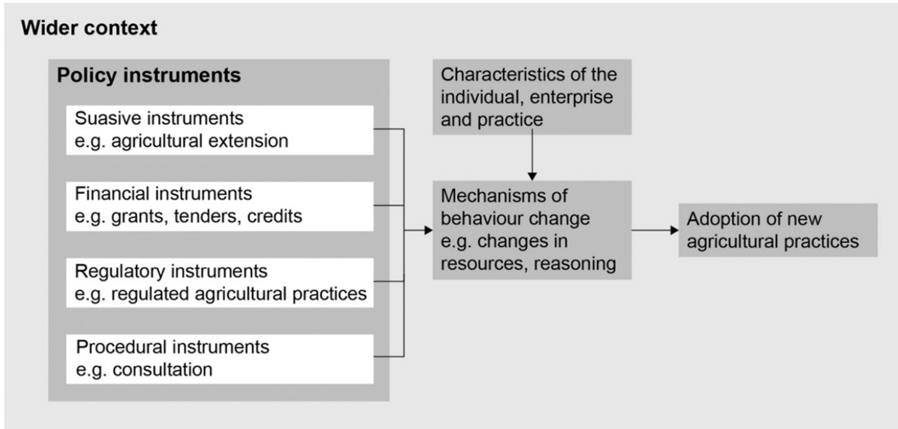

Fig. 2. Conceptual model of policy instruments influencing farmer adoption decisions.

Consistent with the aims of our study, we adopted elements of two complementary review approaches – a *critical review* and *qualitative evidence synthesis*. The first of these approaches aims to extensively (but not systematically) review the literature and critically evaluate its quality, provide analysis, and contribute to conceptual development that embodies existing or derives new theory (Grant and Booth, 2009). The search strategy identified the most significant literature in the field, evaluated their contributions, and produced a narrative, conceptual synthesis. Grant and Booth (2009) note that while a review of this kind "does serve to aggregate the literature on a topic, the interpretative elements are necessarily subjective and the resulting product is the starting point for further evaluation, not an endpoint in itself" (p.97). We also adopted elements of a second approach, a qualitative evidence synthesis. This approach typically employs selective or purposive sampling of the literature, "looks across" individual studies, is narrative and thematic in its synthesis, and is suited to engaging with conceptual models (Grant and Booth, 2009). In our case, the search strategy involved disciplinary teams reviewing the relevant academic literature for specific instruments.[3] In taking this approach, we sought to contribute to evidencing and augmenting the conceptual model of policy instruments and elements within it, described in Fig. 2, above. The focus on narrative synthesis and conceptual model building was critical to our intent to draw across different disciplinary perspectives on the problem in a synthetic and evaluative way. The comparative weakness of the approach used here is the lack of systematicity in more structured approaches, and as such, we do not intend this review to be exhaustive or quantitative.

To review the implementation of policy instruments for water quality improvement in the GBR we also developed a typology of instruments and catalogued the current investments by Queensland and Australian Governments in practice change projects (that is, projects intended to directly influence adoption of practices) (for the period 2017-2022, as known in 2020). Some Australian Government investments extend beyond this period, while others were still being commissioned at the time of analysis and writing. The catalogue of program investments drew on publicly available documentation (see Commonwealth of Australia, 2021; Great Barrier Reef Foundation, 2021; State of Queensland, 2018; State of Queensland and Commonwealth of Australia, 2018b). Budgetary detail prior to the 2017-2022 period was either not available or not readily comparable; however, program reports, evaluation papers, and academic papers were used to identify major trends in the mix of instruments over time (see, for e.g., Australian National Audit Office, 2016; Lloyd Consulting, 2011; Roberts et al., 2018a). Results of the historical analysis were presented to policy officers and revised based on their feedback.

To assess evidence of effectiveness we adopted an explicitly multidisciplinary approach, drawing on academic literature in law, governance, policy and planning, economics, sociology and behavioural psychology, and grey programmatic literature (program and project reports and evaluations). The academic literature was used to identify the mechanisms through which instruments were expected to achieve change. The effectiveness of policy instruments was informed by both academic literature and grey literature. Progress towards water quality and land management targets drew on the annual public report cards (Australian Government & Queensland Government, 2021). Results of each literature review were collated, summarised, and shared between disciplinary teams. A series of workshops were held to clarify disciplinary norms and assumptions, build a shared understanding of relevant policy terms, and discuss findings.

4. Policy instruments

There are many typologies of policy instruments (e.g., Acciai and Capano, 2018; Vargas and Restrepo, 2019). We applied Vedung's (1998) simple "carrot, stick and sermon" typology to describe policy instruments as either financial (carrots), regulatory (sticks), or suasive instruments (sermons). Each instrument can incentivise or disincentivise behaviour. Instruments can be threatened, promised, or implemented—any of which may trigger a behavioural response. Instruments can be applied to different groups within the production chain, such as farmers, agronomists, resellers, mills, or importers/exporters, although in this paper we confine the analysis to instruments used to influence farming practices.

As Vedung (1998) explains in his seminal paper, financial instruments – the carrots – involve either the handing out or taking away of material resources, be they cash or in-kind. Cash (financial) resources can be incentives such as grants or subsidies or disincentives such as fees or taxes. In-kind resources are generally incentives such as free goods or services (such as farm planning support, for example).

Regulatory instruments – the sticks – are the most authoritative instruments in the typology. Regulatory instruments influence behaviour through formal rules and directives that mandate actions in accordance with what is ordered. Regulatory instruments can absolutely prohibit something unconditionally, or can prohibit with exemptions, with permissions (e.g., permits, licenses), or with obligation to notify.

Suasive instruments – the sermons – involve sharing information and knowledge, reasoned argument, and persuasion. Suasive instruments

[3] Disciplinary teams searched academic literature using the search terms 'Great Barrier Reef', 'water quality' and 'agriculture' and terms specific to instruments (e.g., financial instruments included the following terms: tax*, subsidy, subsidies, grant*, tender*, instrument*, incentiv*, PES, payment*) covering the period 2003-2020.

can be applied directly (e.g., providing personal advice or workshops for farmers) or indirectly (e.g., via information sheets and media resources).

The delivery and impact of these three classes of substantial policy instruments are strongly influenced by aspects of governance that affect the behaviour of actors (individuals and organisations) that interact around a policy issue (Klijn and Koppenjan, 2007). Howlett (2019) therefore argued that governance is an additional, procedural class of policy instrument. Procedural instruments include activities such as collaborative planning, capacity-building, knowledge sharing, brokering and conflict management. Communication strategies for behaviour change (e.g., social marketing or choice architecture) (Ewert and Loer, 2020) are another form of indirect instruments that influence the delivery of the three substantive instruments described above. Applied research and development is not considered here as a discrete instrument, but rather a strategy that sits upstream of the instruments employed to encourage adoption.

In summary, there are three broad classes of substantive policy instruments on a scale of increasing authority — suasive, financial, and regulatory — with procedural instruments influencing the delivery and impact of the other instruments (Fig. 3).

Different policy instruments each have distinct logics regarding how they are expected to influence behaviour. However, the assumptions behind individual instruments are often not explicit nor tested empirically (Howlett et al., 2020). Suasive instruments assume that information and persuasion will influence behaviour through building capacity and motivation, while financial instruments assume that behaviour is influenced by the relative costs and benefits of different practices, and regulatory instruments assume that rules and penalties will motivate compliance and adoption of target behaviours (Howlett, 2019; Weber et al., 2014).

In practice, policy makers negotiate the use of policy instruments in the face of political constraints and in the context of the ongoing social impacts of past and ongoing instrument use (Henstra et al., 2020). The mix of policy instruments applied in a particular setting tends to evolve as multiple strategies are "layered" or "bundled" to address emerging needs (Howlett, 2019). It is common for increasingly authoritative instruments to be added to the mix when responses to voluntary approaches are deemed insufficient (Howlett, 2019). The key challenge for governments is therefore to understand how the mix of instrument logics fit the characteristics of the target population to allow a coherent and effective mix of instruments to be deployed. However, achieving this is a significant challenge. Methods to assess the effectiveness of policy instruments or policy mixes are not well established (Weber et al., 2014). Social responses to policy instruments may be context-specific and vary significantly, even within target populations. Behavioural choices are influenced by many factors, change over time, and responses may include various types of fraud and gamesmanship (Howlett, 2020a).

5. Implementation of policy instruments to improve water quality in the GBR

This section describes the policy instruments implemented to improve water quality in the GBR. It draws upon a catalogue of the current mix of instruments employed by state and federal governments (2017-2022) and a review of program implementation over time. The mix of instruments has evolved over the last 18 years (Fig. 4) as state and federal governments have adjusted their programs. Investments in extension services have increased over time and now involve a wide variety of delivery agents including government agencies, natural resource management (NRM) organisations, agricultural industry bodies, and private sector organisations. Early investments were dominated by grants; however, the diversity of financial instruments has increased over time. A small number of market instruments have been trialled (reverse tenders) and credits and offsets are now emerging as new instruments. Direct regulation of agricultural practices was first enacted in 2009, enforcement was suspended with a change in government, then later reinstated and enhanced regulations enacted by the subsequent government in 2019. Procedural governance instruments have also varied over time, with a general trend towards more competitive funding arrangements but also a policy commitment to collaborative approaches. Overall, the network of delivery agents and policy instruments has diversified.

The level of investment in substantive policy instruments seeking to directly influence the adoption of agricultural practices to improve water quality is presented in Table 1, below, and described in the following sections. The total investment catalogued in "on-ground" projects for this period was $390 M (AUD) in real terms (but noting the data limitations described earlier). As the expenditure across years is not known precisely, the results are presented as a proportion of the total investment. The hybrid nature of many investments also creates a challenge – many financial incentives are delivered through extension programs (e.g., grant programs).

5.1. Suasive instruments (extension)

The primary form of suasive instrument employed in the GBR is agricultural extension. Extension services are a critical part of the rural innovation system, bridging agricultural and environmental research and development, policy-making, and the adoption of practices or on-farm technologies, (Pannell et al., 2006). Extension activities includes where public and private sector actors provide "technology transfer, education, attitude change, human resource development, and dissemination and collection of information" (Pannell et al., 2006, p. 1408). Where these efforts seek to proactively work with landholders or farmers to improve water quality or other environmental outcomes through adoption of particular management approaches is referred to as "environmental extension" (Botha et al., 2008).

Extension-type projects have been a feature of GBR programs since the first bilateral Reef Plan in 2003 (State of Queensland and

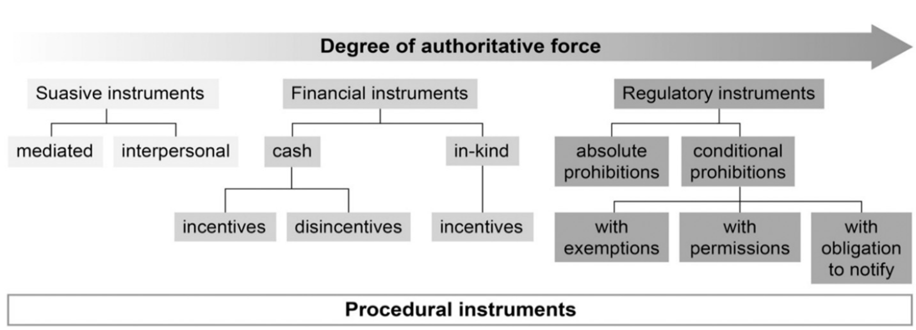

Fig. 3. Policy instrument typology (adapted from Howlett, 2019; Vedung, 1998).

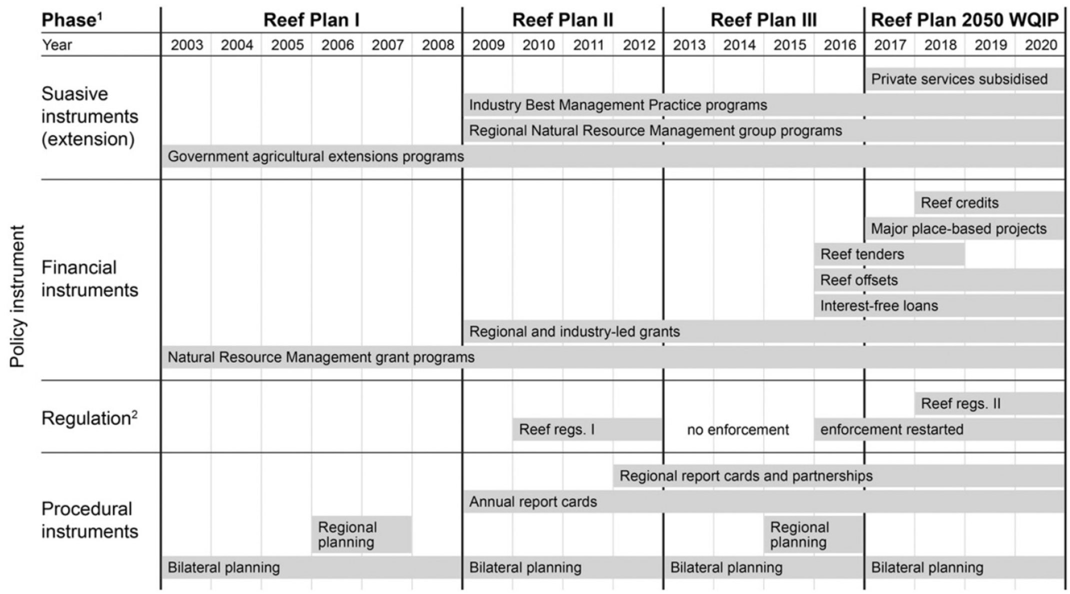

Fig. 4. Timeline of major policy instruments for water quality improvement in the GBR.
Notes: [1]1
[2]2

Table 1
Relative investment in substantive policy instruments to support adoption of agricultural practices for water quality (2017-2022) (source: (see Commonwealth of Australia, 2021; Great Barrier Reef Foundation, 2021; State of Queensland, 2018; State of Queensland and Commonwealth of Australia, 2018b).

Instrument category	Proportion of total investment (2017-2022)
Suasive instruments (extension)	51%
Financial instruments with extension	36%
Financial instruments without extension	3%
Regulation and compliance	4%
Other (remediation of major gullies)	5%

Commonwealth of Australia, 2003). The state Department of Agriculture and Fisheries (DAF) extension services continue to provide a critical role in the GBR extension networks and receive about $30 million (AUD) in the current Queensland Government program (2017-2022) (State of Queensland and Commonwealth of Australia, 2018b). NRM programs have played an increasingly significant role in delivery of extension-type services from 2009 onwards (when NRM investments in the reef were scaled up) (Eberhard et al., 2017; Lane and Robinson, 2009). Best management practice (BMP) programs led by agricultural industry peak bodies received significant additional government support from 2013 onwards (particularly in sugarcane and grazing), which was associated with a change in government and the decision to suspend enforcement of reef regulations (Eberhard et al., 2017). Industry BMPs continue to be a major investment, with more than $20 million (AUD) in the current (2017-2022) program (State of Queensland and Commonwealth of Australia, 2018b), and sugarcane as the largest beneficiary. The Grazing BMP program ceased in 2019 following the peak industry body's decision to delete practice change data (see Smee, 2019b). In addition, a lower level of resourcing has been provided for Banana BMP (starting 2016) and a horticulture BMP program (from 2018) (State of Queensland and Commonwealth of Australia, 2018b).

Over time, the diversity of extension service providers has grown to include non-government, industry and subsidised private advisory services (Table 2), in line with national and international trends in agricultural advisory services (Klerkx, 2020). In our analysis of the current mix of instruments, we found that about 51% of program investments in practice change programs (2017-2022) were invested in extension services, with an additional 36% invested in hybrid extension and financial instruments (such as grant programs).

Table 2
Types of extension providers in the GBR (after Coutts et al., 2017a; Coutts et al., 2017b; Fielke et al., 2020).

Providers	Primary role / focus of advice
Regional natural resource management organisations	Government-funded: program coordination and delivery, awareness, community-based intermediation, environmental improvement
Agricultural peak industry bodies	Producer funded, political representation and member services
Rural research & development corporations	Industry and government funded: research and knowledge transfer for profitability and sustainability of agricultural industries
Productivity services associated with milling districts for sugar cane	Locally or regionally based industry-funded 'boards' seeking enhanced yield and productivity
Private consultants through to large agri-business companies	Commercial agronomy or related advice on inputs, tailored advice for decision-making, resellers of inputs
Public research agencies and universities	Monitoring or modelling effectiveness of interventions; participatory research; science advice
State government officers from agriculture and environment agencies	Applied research, knowledge transfer, engagement, program coordination and delivery, maintenance of state interests

Psychological approaches to behaviour change, such as community-based social marketing (McKenzie-Mohr and Schultz, 2014), also fall within the category of suasive instruments. Despite increasing calls to consider psychological approaches to facilitate adoption of agricultural practices (Hay et al., 2019; Pickering et al., 2017; Pickering et al., 2018; Simmons et al., 2020), these approaches have received limited application in the GBR (except for the Canechanger program).

The trend of greater diversity in the roles, resources, and modes of extension advice to farmers contributes to increasing complexity of advisory arrangements (Blackstock et al., 2010; Phillipson et al., 2016). This growing diversity of providers can have positive outcomes in terms of more individualised advice tailored to specific farm businesses (Birner et al., 2009). However, there are also concerns that the deregulation of extension services over the last 20 or more years has contributed to fragmentation of advice, including a gap between extensionists and the research and development system (Deane et al., 2018; Prager et al., 2016). Indeed, there have been calls for improved coordination, collaboration and training in the advisory system in Australia (Eastwood et al., 2017) and in the GBR (Coutts et al., 2017b; Great Barrier Reef Water Science Taskforce, 2016, p. 4) as a prerequisite for achieving broadscale practice change.

5.2. Financial instruments

Financial instruments involve either the handing out or taking away of material resources, be they cash or in-kind (Vedung, 1998). Financial incentives therefore result in a landholder having more or less financial resources. Different financial instruments achieve this in different ways (positive or negative, direct or indirect), as summarised in Table 3.

Of the suite of financial instruments available (Table 3), our analysis shows that only a subset has been implemented in GBR catchments. The most widely used financial instruments have been those that involve payments from the government or buying agent, in the form of flat rate or competitive grants and subsidies to assist with the costs of changing behaviours. In the early phases of Reef programs (2003–2012) grants were the dominant instrument, delivered initially through NRM programs and then scaled up through NRM and agricultural industry partnerships. In the current investment phase (2017-2022) all grants are provided with or through an extension project. These hybrid instruments (grants plus extension) comprise 36% of the practice change investments in this period. A further 3% of practice change investments were financial instruments without direct extension support (reverse auctions).

As noted above for extension, our analysis shows that recent years have seen a greater diversity of financial instruments and delivery arrangements used. Reef trust tenders trialled the use of multiple rounds of

Table 3
Types of financial instruments.

Type of financial instrument	Example:
More cash available	
Directly through payments by government	• Non-competitive process such as grants or subsidies • Competitive process such as a tender or land purchase
Directly through payments facilitated by the private sector	• For the supply of credits in credit markets such as offsets
Indirectly due to reduced costs	• Rate rebate • Tax concession • Concessional loan • Interest relaxation • Dept swap • Reduced stamp duty
Indirectly due to business support systems	• Innovative insurance products (e.g., yield insurance)
Less cash available	
Directly due to tax or fine	• One off tax or fine for exceeding a set rate of pollution • Incremental per unit over a set rate

[1] Phase is defined by the bilateral water quality plans (State of Queensland and Commonwelath of Australia, 2003; 2009; 2013; 2018a).

[2] Reef regulations under the Environmental Protection Act 1994 (Qld) were passed in 2009 (Great Barrier Reef Protection Amendment Act 2009) and enhanced in 2019 (Environmental Protection (Great Barrier Reef Protection Measures) and Other Legislation Amendment Bill 2019).

Table 4
Summary of financial instruments used in the GBR in last 5 years (source: Commonwealth of Australia, 2021; Great Barrier Reef Foundation, 2021; State of Queensland, 2018; State of Queensland and Commonwealth of Australia, 2018b).

Financial instrument (categories as per Table 3)	Investment source and program	Program and instrument details	Industry (and region) or focus
Payment from government or buying agent (e.g., grant)	Australian Government (Reef Trust)	Reef Trust tenders – competitive grants program	Sugarcane in the Wet Tropics and Burdekin
		Reef Trust Alliance: growing a Great Barrier	Sugarcane, grazing, dairy, horticulture, and broad acre cropping
		Project Uplift Farming Systems Initiative –includes grant funding	Sugarcane growers in Maryborough, South Johnstone, Mulgrave, and Tablelands regions.
		Reef project – includes grant funding	Sugarcane, grazing all regions
	Queensland Government (Reef Water Quality Program)	Farming in Reef Catchments program – provides funding for professional advice for Reef regulations compliance.	Sugarcane, bananas, grazing, grains, and horticulture, new or expanded cropping
		Grazing Resilience and Sustainable Solutions (GRASS) program – offering grants for infrastructure improvements particularly those that improve ground cover.	Grazing in the Burdekin, Fitzroy, and Burnett Mary
	Australian Government (Reef Rescue)	Predominantly a grants program, running from 2008 to 2013	Sugarcane and grazing. All catchments
	Queensland Government (Reef Water Quality Program)	Major Integrated Projects –concerted investment in multiple instruments in specific catchments, including grant funding	Sugarcane and grazing. Wet Tropics and Burdekin
	Queensland Government (Reef Water Quality Program)	Springvale cattle station purchase and conversion to refuge	Grazing, Cape York
Purchase from private sector (e.g., credits)	Australian Government (Reef Trust)	Reef Trust Offsets (Under *the Environmental Protection and Biodiversity Conservation Act 1999*)	All industries all regions if meeting requirements
	Queensland Government (Reef Water Quality Program)	Reef Credits – stewardship payments	
More cash available (e.g., in compensation for increased costs)	Australian Government (Reef Trust)	Project Uplift Farming Systems Initiative – program includes cheap loans, funded by a partner on the project: MSF Sugar	Sugarcane growers in Maryborough, South Johnstone, Mulgrave, and Tablelands regions.

(continued on next page)

Table 4 (*continued*)

Financial instrument (categories as per Table 3)	Investment source and program	Program and instrument details	Industry (and region) or focus
More cash available due to reduced risk	Not used	N/A	N/A
Less cash available due to tax on polluting input or output	Not used	N/A	N/A

market-based instruments in the wet and dry tropics. Market based instruments such as tenders are perceived to address some of the cost inefficiencies of grant-based programs. Several financial instruments supported by the private sector have also emerged – Reef Trust offsets, Reef credits and carbon co-benefits (e.g., Queensland's Land Restoration Fund) and these are not included in the financial figures summarised here. It should also be noted that offsets and carbon projects rely on other legislative instruments – the *Environmental Offsets Act 2014* (Qld) and the *Carbon Farming Initiative Act 2011* (Aust.) respectively. In addition, Reef Trust Project Uplift Farming Systems Initiative, working in partnership with the private sector, provides a mix of financial instruments in the form of both grants and interest-free loans.

5.3. Regulation

Regulation is the development of enforceable rules (often through legislation) in which there is an expectation of compliance (State of Queensland, 2019c). Although the use of regulation to address GBR water quality was first proposed over a decade ago (Great Barrier Reef Protection Amendment Act, 2009 [Qld]), it was not until relatively recently that this featured as a central instrument in the policy approach. The 2009 regulations were highly contested by agricultural industry peak bodies, and with a change of government in 2012 it was announced that the regulations were "on ice" and all enforcement activities would cease (and investments in industry BMPs were increased) (Eberhard, 2018). After the next election (2015) and upon recommendation by the Great Barrier Reef Water Science Taskforce (2016), enforcement was reinstated and regulations were enhanced (*E*Environmental Protection (Great Barrier Reef Protection Measures) and Other Legislation Amendment Act, 2019 [Qld]).

These have again been highly contested despite extensive industry consultation (Hamman and Deane, 2018; Parliament of Australia, 2020). The Queensland Government is currently investing approximately 4% of practice change funding in GBR-specific regulation and compliance activities (Table 1). Despite calls from scientists (Brodie and Pearson, 2016; Gardner and Waschka, 2012; Kroon et al., 2016), the Australian Government has not exercised its capacity to use regulatory instruments to encourage adoption of improved water quality practices in the GBR.

The current regulatory approach targets commercial cropping and grazing practices across the GBR catchment by way of Chapter 4A of the Environmental Protection Act, 1994 (Qld). The regulatory provisions have many components of what may be described as a "command-and-control" approach (Nelson, 2010). Under this model, the Queensland Government is the dominant regulatory actor and criminal sanctions are to be imposed in the event of non-compliance, but implemented according to staged enforcement guidelines (State of Queensland, 2019b). The rules in Chapter 4A provide that landholders must adhere to certain minimum agricultural standards. There are prescribed methodologies, in the case of sugarcane and banana farming, for the amount of nitrogen and phosphorous that can be applied to a crop. A farm budget must be developed, and farmers should also make and keep records relating to farm management. Examples of the regulatory requirements for sugarcane cultivation (State of Queensland, 2019a) are shown in Table 5, below.

Despite the main focus of Chapter 4A being a command-and-control style-model (Nelson, 2010), there are also provisions that reflect self-regulatory or co-regulatory aspects (Davis, 2019; Sinclair, 1997), for example, by allowing farmers to complete a recognised accreditation program such as the industry BMP program (see section 82; Part 5A Environmental Protection Act, 1994 (Qld)) in order to comply with the rules. Accredited standards allow for farmer flexibility in achieving water quality outcomes and are akin to less intrusive forms of regulation, such as management-based regulation (Coglianese and Lazer, 2003) or enforced-self-regulation (Braithwaite, 1982). These softer forms of regulation allow landholders flexibility in how they meet regulations, and thereby aim to improve engagement and compliance (Coglianese and Lazer, 2003, p. 1). For the prescribed sugarcane conditions listed above, a farmer may, on occasion, choose their own measure to demonstrate compliance with the standard conditions (State of Queensland, 2019a).

5.4. Procedural instruments

In its broad interpretation, governance (or metagovernance) refers to the design and implementation of all policy instruments employed by the government (Rhodes, 2012). Governance is also used to describe a specific mode of governing, that is also known as network governance or collaborative governance (Colebatch, 2014). In this usage, governance refers not to the substantive policy instruments (regulation, incentives, information) but to procedural instruments that influence the behaviour of the network of actors (organisations and individuals) that interact around a policy issue (Klijn and Koppenjan, 2007). This is how the term governance is used in this context – the *use of procedural instruments by governments to facilitate productive relations with the network of GBR water quality stakeholders*.

Bilateral coordination between Queensland and Australian Governments is an important component of GBR governance, and both governments employ a variety of procedural instruments to facilitate

Table 5
Examples of regulated agricultural practices in the GBR (State of Queensland, 2019a).

Farming Activity	Condition number	Regulatory Requirement
Broadcast application of fertiliser.	SC1	Ground-based broadcast application of fertiliser containing nitrogen must not occur on the agricultural property.
Erosion and sediment control.	SC3	Erosion and sediment control measures to minimise soil loss and surface water run-off must be implemented and maintained on the agricultural property.
Nitrogen and phosphorus fertiliser application.	SC6	Soil testing and analysis must be carried out within the 12 months prior to fertiliser being applied to: a) a new plant cane crop; or b) a new cane crop cycle if no fertiliser is applied to the plant crop, in accordance with the administering authority's latest version of 'Prescribed Methodology for Sugarcane Cultivation'
Farm Nitrogen and Phosphorus Budget	SC18	The application rate of fertiliser applied to the agricultural property must not exceed the whole of farm nitrogen amount or the whole of farm phosphorus amount in the Farm Nitrogen and Phosphorus Budget.
Record Keeping	SC24	The person carrying out the agricultural activity must keep all relevant primary documents related to the agricultural ERA records.

stakeholder engagement and participation in water quality programs. It is important to note that water quality is one of several large and complex issues within the broader policy suite of GBR governance, which has been described as polycentric due to the large number of actors, nodes of authority, management and decision-making (Morrison, 2017a; Morrison, 2017b). Table 6 provides examples of procedural governance instruments used in the GBR, arranged in terms of their primary policy functions (knowledge sharing, policy design, implementation, monitoring, and reporting).

GBR programs have always relied heavily on external delivery agents for program implementation. The development of regional water quality improvement plans engaged regional NRM organisations and industry partners, and ultimately led to a major delivery partnership, the Reef Alliance (Eberhard et al., 2017). Stakeholder engagement has varied over time with successive governments, and the increasing use of competitive funding arrangements has impacted stakeholder networks (Vella et al., 2017; Vella et al., 2015). Peak agricultural industry bodies receive substantial financial support for industry BMP programs ($20 million AUD in the current 2017-2022 program) (State of Queensland and Commonwealth of Australia, 2018b), but have strongly advocated against reef regulations and reef science more generally (Smee, 2019a, 2019c, 2019d). The peak grazing industry group, Agforce, deleted over 10 years' of farmers practice data (Kennedy, 2019; Smee, 2019b) on the basis of perceived risks of graziers' data being used for compliance, an act which ultimately led to the collapse of the Grazing BMP partnership and program.

The other major investment in collaborative arrangements in the GBR are regional report card partnerships, which engage regional stakeholders in the delivery of annual water quality report cards. Queensland and Australian Governments currently invest $11 million (AUD) in regional report cards over 2017-2022 (State of Queensland and Commonwealth of Australia, 2018b), and other partners also contribute cash and in-kind resources.

6. Prioritising effort to achieve outcomes

The source and impact of water quality pollutants varies across the GBR. Sugarcane (400,000 ha) is the dominant source of dissolved inorganic nitrogen and pesticides, while rangeland grazing (3.1 M ha) contributes the most sediment (Waterhouse et al., 2017). Targets for improved water quality in the GBR are set based on the five lines of evidence, including marine monitoring programs, paddock and catchment modelling, catchment water quality monitoring and reported adoption of management practices (Carroll et al., 2012; Waters et al., 2014). A series of water quality frameworks that describe the relative water quality benefits of different practices have been developed for the major agricultural industries of the GBR (see, for e.g., Australia Department of Environment & Queensland Department of Environment and Science, 2013a; Australia Department of Environment & Queensland Department of Environment and Science, 2013b). Targets are revised periodically, and progress is reported in annual report cards (State of Queensland and Commonwealth of Australia, 2020a, 2020b). More sophisticated approaches to understanding the cost-effectiveness of different investments, including adoption rates, time lags to water quality benefits, costs, and risks are emerging (Rolfe et al., 2018c; Star et al., 2018).

Table 6
Procedural governance instruments used in the GBR (Commonwealth of Australia, 2021; Great Barrier Reef Foundation, 2021; State of Queensland, 2018; State of Queensland and Commonwealth of Australia, 2018b).

Primary policy function	Procedural instrument used in the GBR
Sharing or promoting science and knowledge	Independent science panel Technical working groups (e.g., human dimensions, pesticides, sediment etc.) Periodic (5-yearly) scientific consensus statements Annual Reef Synthesis workshops Reef 2050 Communication Network Regular webinars
Policy design	GBR Water Quality Taskforce Reef 2050 Advisory Committee (stakeholders) GBR and regional water quality improvement plans Formal public consultation (plans, regulations)
Policy implementation	Commissioning delivery of projects including: • Co-design of projects • Facilitating/incentivising collaborative projects • Funding a diversity of service providers • Co-delivery of some programs
Monitoring and evaluation	Collaborative/commissioned monitoring activities (joint investigations) GBR report card Regional report card partnerships

7. Evidence of outcomes – progress towards targets

The bilateral Reef Water Quality Improvement Plan seeks the outcome that "good water quality sustains the outstanding universal value of the Great Barrier Reef, builds resilience, improves ecosystem health, and benefits communities" (State of Queensland and Commonwealth of Australia, 2018a, p. 15). The plan also commits to a series of water quality and land management targets (Table 7) developed to meet water quality objectives for the downstream marine environment (Brodie et al., 2017).

Progress against targets has been tracked since 2008-09, and practice benchmarks have been reviewed and updated (most recently in 2016) (State of Queensland and Commonwealth of Australia, 2020a). Water quality programs (including compliance, agricultural extension and grants programs) record the spatial adoption of practices, and aggregated results are reported (with modelled water quality benefits) annually (State of Queensland and Commonwealth of Australia, 2020a). The most recent report card was released in August 2020 and reported on progress up to June 2019 (State of Queensland and Commonwealth of Australia, 2020b). Progress against targets for key water quality and management practice metrics show slow progress, clearly insufficient to meet 2025 targets (Table 8).

Confidence in the reported management practice adoption figures is "moderate" (State of Queensland and Commonwealth of Australia, 2020a). There is no mechanism to capture "background" practice change, that is, adoption that occurs outside of reef programs (thus,

Table 7
Reef Water Quality Improvement Plan targets (source: State of Queensland and Commonwealth of Australia, 2018a, p. 15).

Category	2025 targets
Water quality	60% reduction in anthropogenic end-of-catchment dissolved inorganic nitrogen loads 25% reduction in anthropogenic end-of-catchment fine sediment loads 20% reduction in anthropogenic end-of-catchment particulate nutrient loads Pesticide target: To protect at least 99% of aquatic species at the end-of-catchments
Land and catchment management targets	90% of land in priority areas under grazing, horticulture, bananas, sugarcane and other broad-acre cropping are managed using best management practice systems for water quality outcomes (soil, nutrient, and pesticides) The management of urban, industrial, and public land uses for water quality shows an improving trend The extent of riparian vegetation is increased No loss of the extent of natural wetlands 90% of grazing lands will have greater than 70% ground cover in the late dry season

Table 8
Summary of 2019 progress against targets (State of Queensland and Commonwealth of Australia, 2020b).

Category	Parameter	Target	2019 progress	Overall progress	Grade
Water quality	Dissolved inorganic nitrogen	60% reduction	4.3% reduction	25.5% reduction	A "very good"
	Sediment	25% reduction	0.2% reduction	14.6% reduction	E "very poor"
Management practices	Grazing practices	90% adoption	0.4% reduction	36.2% adoption	D "poor"
	Sugarcane practices	90% adoption	2.9% reduction	12.7% adoption	E "very poor"

adoption may be under-reported), while at the same time, overly optimistic reporting by project managers and the potential for dis-adoption suggests that adoption may be over-reported (State of Queensland and Commonwealth of Australia, 2020a). Without knowing the background level of change, it is very difficult to assess the additionality of the changes recorded; that is, whether adoption would have occurred without the program or policy instrument (Pannell and Claassen, 2020). Indeed, adoption itself is a dynamic process involving processes of trialling and partial adoption, as well as adoption and dis-adoption (de Oca Munguia et al., 2021). Farmers may interact with multiple programs and providers, making attribution of adoption decisions to any single instrument problematic. Thus, despite the sophisticated system of tracking and accounting for program outcomes, actual estimates of adoption remain somewhat uncertain and attribution to individual policy instruments and additionality hard to demonstrate.

8. Evidence of effectiveness – GBR instruments

Acknowledging that overall progress towards targets for the adoption of practices is less than what is required to achieve water quality outcomes for the marine environment, we examined evidence of the effectiveness of individual instruments in contributing to the desired change. We considered the academic literature first, and then programmatic grey literature (program reports and evaluations) to find evidence of effectiveness (noting that evaluation reports are often not publicly available).

Most government-funded extension projects are required to evaluate and report their achievements and usually rely on measures such as delivery of services, farmer participation, satisfaction, and general feedback (although measures are not necessarily consistent between projects) (Roberts et al., 2020). For example, Grazing BMP reported meeting and surpassing targets for producer participation; increased knowledge, skills, and awareness; intention to change; and actual change in management practices (Willis et al., 2017). While most participating producers (76%) self-reported doing something differently as a result of engaging in this program, there is limited information about the specific type and scope of practice change, and low levels of uptake of independent accreditation (Brown, 2017; Willis et al., 2017). Similarly, there is weak evidence of practice change from extension efforts in sugarcane "the success of any extension program is measured in its lasting effectiveness and as such cannot be fully measured at this point in time" (Royle and Di Bella, 2017, p. 192). Projects generally target growers (either based on water quality hot spots and/or willingness to engage) (Hepburn and Nash, 2019; Royle and Di Bella, 2017). Approaches include one-on-one, peer-to-peer, collaborative monitoring, smart phone decision systems (Davis, 2019; Rouse and Davenport, 2017; Thorburn et al., 2019), and coordination of extension networks (Coutts et al., 2017a; Coutts et al., 2017b); however, evidence that demonstrates their contribution to adoption outcomes remains elusive.

Despite the body of literature studying the economics of changing land management practices within the GBR region, evidence specifically relating to the effectiveness of financial instruments in the GBR and elsewhere (see Olmstead, 2010) is limited. Existing literature either evaluates effectiveness using modelling or theoretical analysis (e.g. Star et al., 2019), relates to the cost of achieving behaviour change/pollution abatement without focusing on the specific instrument that would be used to finance that cost (e.g. Rolfe and Harvey, 2017; Star et al., 2013; Wilkinson et al., 2019), or the cost effectiveness of instrument design (within instrument) (e.g. Rolfe and Windle, 2011a). Within the literature focussed on specific finanical instruments, very few reports focus on the effectiveness of actually changing landholder behaviours and achieving additionality (change from what would have occurred in the absence of the incentive) (e.g. Greiner, 2015). Furthermore, due to the nature of the financial instruments implemented within the GBR region, the literature has a strong focus on grants and subsidies, with only the theoretical/modelling literature focusing on other instruments.

Indicators of effectiveness include uptake levels, whether the program achieves additionality, whether effects persist beyond the project, and whether crowding in or crowding out effects (where people's intrinsic motivations to adopt are either reinforced or undermined) occur. Whitten and Langston (2020) evaluated the results of the Reef Trust reverse tenders for nitrogen reduction that contracted 5% of cane farmers and achieved a 14% reduction in fertiliser use in those areas. Whitten and Langston's (2020) findings support previous findings of the cost effectiveness of competitive tenders when compared with regulatory approaches or the use of flat rate grants to achieve water quality improvements (see Rolfe and Windle, 2011b). Evaluations of cost-effectiveness clearly demonstrate that heterogeneity of farms and farmers drives large differences in costs and water quality benefits (Rolfe and Windle, 2011a, 2016; Rolfe et al., 2018a; van Grieken et al., 2019; Wilkinson et al., 2019). Alarmingly, Rolfe et al. (2018b) revealed that a large proportion (~25%) of on-farm projects funded in 2008-2013 failed to generate any significant pollutant reduction. In contrast, (van Grieken et al., 2014) found that the same scheme was effective in bringing forward the implementation of improved practices, but the requirement for matching up-front capital costs was a constraint. Greiner (2015) found the 2008 Lower Burdekin Water Quality Tender to be both effective and efficient due to having achieved additionality, persistence, and generated crowding in effects (where people's intrinsic motivations to adopt are reinforced by the program), although some shortcomings in the scheme's administration were also identified.

Credit trading schemes such as offsets, cap and trade, and general credit trading are either not currently applied in GBR catchments or not sufficiently advanced for evaluation. In other areas, including New Zealand, U.S.A., and Canada credit schemes have proven effective at reducing nutrient runoff from farms (Doole, 2012; Rosas et al., 2015; Spicer et al., 2021), while Smart et al. (2016) demonstrated that there is sufficient variability in gross margins to drive an active nitrogen credit trading market in the Tully catchment of the GBR.

Regulation is widely seen as a critical component of the broader policy mix required to combat water quality decline (see Brodie and Waterhouse, 2012; Coggan et al., 2021; Dale et al., 2017; Great Barrier Reef Water Science Taskforce, 2016; Gunningham and Sinclair, 2004; Gunningham and Sinclair, 2005; Tan and Humphries, 2018; Taylor and Eberhard, 2020; van Grieken et al., 2013). Regulation is most often seen as a measure of last resort (the regulatory "gorilla in the closet" (Rees, 1997, p. 519). Whilst studies have been published on the impact of environmental law and regulation on farming communities across Australia (see e.g. Bartel and Barclay, 2011), including self-regulation in the Australian cotton industry (Farquharson et al., 2008; Gunningham, 2004), there are no published comprehensive empirical accounts on how Queensland farmers respond or are likely to respond to regulatory oversight of water quality measures in the GBR context.

The introduction of regulation of agricultural practices within the GBR catchments has been met with resistance from the agricultural sector (see Deane et al., 2018; Eberhard, 2018; Gardner and Waschka, 2012; Hamman and Deane, 2018; Waschka and Gardner, 2016). Despite this, public reporting of compliance data shows that staged compliance activities has been effective at raising awareness of regulatory obligations and driving compliance with prescribed activities. Levels of compliance vary significantly between catchments, with areas of high BMP participation also showing high levels of compliance (noting that BMP accreditation is deemed to be compliant). At first visit, only 9% of 692 sugarcane farmers inspected in 2016-2020 were compliant, and 55% were non-compliant (the balance were mostly enrolled in a practice change program or were BMP-accredited) (State of Queensland, 2020). At follow up visits (with those deemed non-compliant at first visit), only 25% remained non-compliant (the rest had either complied or enrolled in a practice change program) (State of Queensland, 2020). These results relate to the 2009 regulations, which were strengthened in 2019 (results of compliance for the 2019 regulations are not yet available). Regulation of pesticides in Australia (separate to the direct regulation of farming practices for water quality) has also been critiqued as deficient "ad-hoc, case by case and very slow" (King et al., 2013, p. 54).

Procedural governance instruments influence the delivery of the substantive instruments, which makes their contribution to adoption outcomes difficult to assess. However, there is some evidence that governance approaches in the GBR have contributed to the quality and acceptance of policy outputs and implementation capacity. A longitudinal study of GBR governance found that stakeholders had brought additional knowledge to the policy design process, including an understanding of policy issues, potential impacts on stakeholder interests, and local knowledge that enabled policy be tailored to local conditions (landscapes, farming systems, communities) (Eberhard, 2018; Vella and Baresi, 2017). While the degree of collaboration between policymakers and stakeholders has varied over time, a variety of forums have worked to improve the credibility and legitimacy of knowledge used for policy decisions. For example, community engagement in water quality planning in the GBR has contributed to building trust, as well as contributing to local knowledge and growing commitment (Bohnet, 2014; Hill et al., 2015), although the role of local knowledge in science-based planning and implementation is ambiguous, and local engagement requires careful facilitation by trusted agents (Kroon et al., 2009; Taylor and van Grieken, 2015).

Agricultural industry bodies and regional natural resource management groups have provided significant delivery capacity for over a decade (Eberhard et al., 2017) and have also been adept at collectively influencing policy design decisions (Eberhard, 2018; Robinson et al., 2010). However, changes to government funding models and periodic adjustments of investment priorities can undermine collaboration, reducing "front line:" delivery capacity (Campbell, 2016; Tennent and Lockie, 2013).

In recent years, industry resistance to water quality regulation and reef science and policy has generally been acute (see, for example Smee, 2019a; Smee, 2019b) although peak agricultural industry bodies continue to play significant implementation roles, particularly through BMP programs. Participation in reef policy programs can be seen as both a risk and an opportunity for these organisations representing farmers (Taylor et al., 2010). The legitimacy of these organisations in representing their members' interests can be challenged (Taylor and Lawrence, 2012) as they grapple with determining their advocacy roles in relation to environmentally friendly farming practices.

9. Discussion

Policy instruments to encourage adoption of more sustainable farming practices in the GBR have evolved and diversified over the last 20 years. It is clear that water quality targets will not be achieved, and there is little evidence available to assess the effectiveness of the current suite of instruments. Although a diversity of extension services and providers are funded, evaluation has been project-based and reliant on weak descriptive measures such as participation and satisfaction (Roberts et al., 2020). Financial instruments have mostly been grants or subsidies, and while these funds have been disbursed, it is difficult to determine whether additionality has been achieved. Cost-effectiveness studies show that heterogeneity of landholders and enterprises (as well as practices) means that costs to achieve water quality outcomes are highly variable, and this argues for the greater use of market-based instruments. Several new financial instruments (credits, offsets) are emerging; however, no performance data are available yet. Regulation has been highly contested, and public media campaigns by peak agricultural industry groups appear to be impacting on participation in voluntary programs. Nevertheless, early compliance results indicate that regulations are driving change, albeit at the lower end of the practice spectrum.

Improving the evidence of the effectiveness of policy instruments is highly desirable, but not without its challenges. Adoption of new farming practices is a dynamic and evolving process (de Oca Munguia et al., 2021). Evaluating types of policy instruments and their interactions is complicated in the GBR because instruments are often hybrids of policy types, numerous, and interdependent, which means that farmers can engage with multiple instruments, services, and providers. While practice change adoption is measured in the GBR, outcomes cannot be readily attributed back to specific instruments or programs. Implementation of policy instruments is also targeted at water quality hot spots or willing farmers rather than at the broad scale. An instrument that effectively encourages adoption of a practice for one cohort of farmers may not generate the same behavioural response for other practices and/or other farmer cohorts. Rather than seeking to determine the effectiveness of specific instruments, we argue that there is a need to better understand the fit between the mix of instruments and target audiences. In other words, between instruments, the diversity of landholders, and desirable practices. In classic realist framing, this is "what works for who, and why".

Policy toolkits describe a mixture of instruments applied with care in specific social contexts and at different levels to incentivise and disincentivise behaviour towards achieving water quality and environmental benefits (Osborn and Datta, 2006; Taylor et al., 2010; Vella and Dale, 2014). Overall, we found that while the water quality programs in the GBR have some elements of a policy toolkit approach, policy has been dominated by a few instruments, namely, extension and grant programs. Within these classes of instrument, the diversity of service providers has increased over time and some new sub-types of instruments are under development or modifications to existing instruments recently made (e.g., reef credits, enhanced regulations). Without robust measures of policy instrument effectiveness, it is unclear how GBR policy makers can refine and improve the policy instrument mix.

Individuals will respond to policy instruments differently, and single instruments are likely to influence only a part of the target population (Weber et al., 2014). Factors that drive the fit between policy instruments and audiences include the characteristics of landholders (such as values, risk tolerance, financial position), the clarity of action required (such as the observability of targets, the ease and cost of implementing actions), and the extent to which implementation is supported (such as local capacity, and socialisation). Understanding the influence of these characteristics in mediating instrument effectiveness in the GBR is a significant gap. Evidence from the GBR is also relatively silent on whether policy instruments have facilitated additional behaviour change that would not have occurred anyway, whether they have reinforced or undermined intrinsic motivations (crowding in or crowding out effects), and whether they have generated positive or negative spill over effects, such as changes in behaviours beyond the site of the initial action.

A stronger understanding of the assumed and operationalised mechanisms of behaviour change of each instrument would enable the assessment of perceived versus expected performance (Weber et al., 2014). For example, agricultural extension broadly seeks to achieve behaviour change through sharing information and persuasive argument (Pannell and Zilberman, 2020). Different models of extension emphasise different relationship configurations between extension agents and farmers, and how these influence knowledge transfer (Black, 2000). Financial incentives are an intended substitute for missing monetary signals for public goods and services, using either reward or compensation (beneficiary pays) or penalties (polluter pays) to change the financial proposition of adopting a practice. Regulation can drive compliance on the basis of economic rationalism (Scholz, 1984). However, others argue that deterrence offers only a partial explanation, and a more complex suite of tangible and intangible motivations is involved (May, 2004; Parker and Nielsen, 2017; Sutinen and Kuperan, 1999). Like the other instruments, a range of regulatory models emphasise different assumptions about compliance behaviours.

Several authors have called for stronger regulation of land use and land management practices in the GBR (see for e.g., Brodie et al., 2019; Kroon et al., 2016; Shellberg, 2021). Earlier, we described the resistance of peak agricultural industry bodies to the current regulations, reef science in general, and the sharing of data about current farming practices. This suggests a real risk of regulatory capture, where political lobbying by interest groups can water down regulatory standards (Deane et al., 2018). Nonetheless, the social and cultural dimensions of behaviour change remain key determinants of adoption decisions in response to coercive or voluntary instruments. Hamman and Deane et al. (2018) agreed with PIckering et al. (2017, p. 9) that "although guidelines, targets and regulations can be effective augmentations to a behaviour change strategy, they are rarely fully effective in their own right" (p. 9).

Policy mixes are required to deal with heterogenous target audiences, different forms of market failure, complex behavioural responses, and political imperatives (Bouma et al., 2019). However, each additional instrument has associated costs as well as benefits. Interactions between policy instruments overlap in time and space. Variations in community and regional contexts, delivery networks, and implementation reinforce the challenge of unpacking the impact of policy mixes.

Capano (2020) and others (see Busetti and Capano, 2020; Howlett, 2020b; Olejniczak et al., 2020) have advocated for a mechanistic approach to understanding the series of cause-effect processes that link policy mix design, implementation, heterogenous contexts and behavioural response outcomes. Howlett (2020b) called for a more sophisticated "compliance regime" that reflects a deep understanding of the diversity of target audience attitudes and behaviours and likely responses to policy instruments. Adding additional instruments has associated costs, while unpacking policy objectives and instruments offers the benefit of better understanding the potential benefits of instrument mixes (Bouma et al., 2019).

Returning to the evidence from the GBR, evaluating the effectiveness of individual policy instruments or a mix of policy instruments is clearly a significant challenge shared with similar agri-environmental policies elsewhere. Our analysis illustrates the limited evidence available to judge, manage, and adapt Reef programs. The multi-disciplinary approach to the review revealed the distinct and often separate theoretical stances or assumptions between studies from different disciplines, and the potential to enhance the understanding of policy efficacy through greater multi-disciplinary collaboration. The integration of insights highlighted the need to link behavioural science models of adoption in a mechanistic way to the logics that exist within the different instruments that themselves derive from different disciplinary foundations. However, linking these behavioural and instrument-based logics is difficult, given the high levels of heterogeneity among farmers, farm enterprises, and contexts across the Reef. Thus, we concur with Howlett (2020b) that better policy design requires a better understanding of the target audiences, and advocate for the value of a multi-disciplinary approach that combines expertise across legal, psychological, social, economic, and governance domains.

Multi-disciplinary approaches offer their own challenges in integrating terminologies, knowledge, and insights. Modelling tools have been developed with the aim of quantifying the impact of changes in scenarios with complex interactions and have a proven track record in the context of environmental policy evaluation (Ames et al., 2005; Barton et al., 2008; Simmons et al., 2018). Suitable modelling approaches for policy instrument analysis would need to clearly demonstrate the relationships between components, accommodate expert data, provide some measure of uncertainty (Milner-Gulland and Shea, 2017), and ideally, facilitate a participatory approach that allows for stakeholder review and contributions (Benham and Daniell, 2016).

Multiple modelling approaches are useful for situations with complex conceptual interactions, including Bayesian networks (Kiss et al., 2020; Liu et al., 2017; Shenton et al., 2010), fuzzy cognitive models (Baker et al., 2018; Game et al., 2018), and systems dynamics (Baker et al., 2017; Raymond et al., 2011). These approaches are based on conceptual models that can graphically represent relationships between system components. Both the structure of the model (representing the direction of the interactions between the various factors) and the strength of the interactions can be derived from analysis of empirical data or expert elicitation. Network models are particularly useful for understanding how different assumptions about a system affect the impact of various policy approaches. We therefore propose a network modelling approach to explore the effects of policy instruments on diverse farmer cohorts in the GBR, allowing the integration of disciplinary and stakeholder expertise and data (where available). Such an approach would build on the conceptual framework presented earlier (Fig. 2) and unpack the pathways of impact through which policy instruments influence the adoption of management practices in diverse contexts (difference landholder cohorts and different land management practices). Elements of existing models that partially address the policy instrument question (such as INFFER (Pannell et al., 2009) or ADOPT (Kuehne et al., 2017)) could be incorporated into a network modelling approach. The capacity to explore scenarios would provide an opportunity to test a model against historical evidence and anticipate the potential benefits and risks of future scenarios. Such an approach could reconcile and synthesise diverse sources of evidence and facilitate the identification of critical knowledge gaps and assumptions that need to be addressed to enable policy instruments to be adjusted for greater impact.

10. Conclusion

Governments in Australia and internationally are investing in policy instruments to facilitate the adoption of more sustainable farming practices for productivity and conservation benefits. Policy toolkits have long been advocated, and policies typically progress over time from voluntary instruments to financial incentives and more authoritative instruments such as regulation. Australia's GBR is a case study in sustained investment in an evolving mix of policy instruments. Despite this, progress towards behaviour change targets remains slower than hoped.

Our critical realist evaluation of policy instruments in the GBR used a critical multi-disciplinary literature review and analysis of different types of instruments and the evidence of their effectiveness. Though water quality programs in the GBR have primarily relied on extension and grants, there has been some diversification in recent years. We found that the effectiveness of the mix of policy instruments is difficult to evaluate. This is due in part to the absence of a clear articulation of how instruments expect to influence farmer decision-making, and also to limited evidence linking policy instruments to behaviour change. This inability to assess the effectiveness of GBR policies is contributing to the slow progress in addressing water quality, despite the continuing and increasing efforts of policy activity by governments over the last 20 years.

We conclude that there are substantial gaps in understanding of policy mechanisms and frameworks to measure policy impacts at a level that can inform the design and implementation of a more effective policy toolkit. To accelerate progress in the GBR, we recommend that governments improve the evidence base for the evaluation of policy instruments and their impact on farmer behaviour so that efficacy can be assessed and enhanced. This must entail deeper understanding about how different policy instruments are expected to influence adoption decisions about a variety of practices by diverse farming cohorts. Recognising the evidentiary constraints, we propose a modelling approach tied to an enhanced monitoring program to build on the existing evidence and further interrogate the mechanisms through which policy instruments are expected to influence behaviour, integrating multidisciplinary and stakeholder knowledge to explore and test policy scenarios.

CRediT authorship contribution statement

Rachel Eberhard: Conceptualization, Methodology, Data curation, Formal analysis, Investigation, Writing – original draft, Writing – review & editing, Visualization, Project administration, Funding acquisition. **Anthea Coggan:** Methodology, Data curation, Formal analysis, Investigation, Writing – original draft, Writing - review & editing. **Diane Jarvis:** Methodology, Data curation, Formal analysis, Investigation, Writing – original draft, Writing - review & editing. **Evan Hamman:** Methodology, Data curation, Formal analysis, Investigation, Writing – original draft. **Bruce Taylor:** Conceptualization, Methodology, Investigation, Writing – original draft, Writing – review & editing. **Umberto Baresi:** Methodology, Data curation, Formal analysis, Investigation. **Karen Vella:** Conceptualization, Project administration, Funding acquisition, Writing - review & editing. **Angela J. Dean:** Methodology, Investigation, Writing – original draft. **Felicity Deane:** Methodology, Investigation, Writing – original draft, Writing - review & editing. **Kate Helmstedt:** Methodology, Investigation, Writing – original draft. **Helen Mayfield:** Methodology, Investigation, Writing – original draft.

Declaration of competing interest

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References

Acciai, C., Capano, G., 2018. Climbing down the ladder: a meta-analysis of policy instruments applications. In: IPPA International Workshops on Public Policy. University of Pittsburgh.
Alons, G., 2017. Environmental policy integration in the EU's common agricultural policy: greening or greenwashing? J. Eur. Publ. Policy 24 (11), 1604–1622. https://doi.org/10.1080/13501763.2017.1334085.
Ames P., D., Neilson T., B., Stevens K., D., Lall, U., 2005. Using Bayesian networks to model watershed management decisions: an East Canyon Creek case study. Journal of hydroinformatics 7 (4), 267–282. https://doi.org/10.2166/hydro.2005.0023.
Australia Department of Environment & Queensland Department of Environment & Science, 2013a. Reef Plan Paddock to Reef Grazing Water Quality Risk Framework. Queensland Government. http://www.reefplan.qld.gov.au/measuring-success/paddock-to-reef/assets/paddock-to-reef-grazing-water-quality-risk-framework.pdf.
Australia Department of Environment, & Queensland Department of Environment and Science, 2013b. Reef Plan Paddock to Reef Sugarcane Water Quality Risk Framework. Queensland Government.
Australian Government, 2020. Reef 2050 Long-term Sustainability Plan. Public Consultation Draft. Australian Government.
Australian Government & Queensland Government, 2021. Reef 2050 Water Quality Improvement Plan - Reef Report Cards. Queensland Government. https://www.reefplan.qld.gov.au/tracking-progress/reef-report-card.
Australian National Audit Office, 2016. Reef Trust Design and Implementation. Australian National Audit Office.
Baker, C.M., Gordon, A., Bode, M., 2017. Ensemble ecosystem modeling for predicting ecosystem response to predator reintroduction. Conserv. Biol. 31 (2), 376–384. https://doi.org/10.1111/cobi.12798.
Baker, C.M., Holden, M.H., Plein, M., McCarthy, M.A., Possingham, H.P., 2018. Informing network management using fuzzy cognitive maps. Biol. Conserv. 224, 122–128. https://doi.org/10.1016/j.biocon.2018.05.031.
Bartel, R., Barclay, E., 2011. Motivational postures and compliance with environmental law in Australian agriculture. J. Rural. Stud. 27 (2), 153–170. https://doi.org/10.1016/j.jrurstud.2010.12.004.
Barton, D., Saloranta, T., Moe, S., Eggestad, H., Kuikka, S., 2008. Bayesian belief networks as a meta-modelling tool in integrated river basin management — Pros and cons in evaluating nutrient abatement decisions under uncertainty in a Norwegian river basin. Ecol. econ. 66 (1), 91–104. https://doi.org/10.1016/j.ecolecon.2008.02.012.
Benham, C.F., Daniell, K.A., 2016. Putting transdisciplinary research into practice: a participatory approach to understanding change in coastal social-ecological systems. Ocean Coast. Manag. 128, 29–39. https://doi.org/10.1016/j.ocecoaman.2016.04.005.
Birner, R., Davis, K., Pender, J., Nkonya, E., Anandajayasekeram, P., Ekboir, J., Benin, S., 2009. From best practice to best fit: a framework for designing and analyzing pluralistic agricultural advisory services worldwide. J. Agric. Educ. Ext. 15 (4), 341–355.
Black, A., 2000. Extension theory and practice: a review. Anim. Prod. Sci. 40 (4), 493–502.
Blackstock, K., Novo, P., Byg, A., Creaney, R., Bourke, A.J., Maxwell, J., Waylen, K.A., 2020. Policy instruments for environmental public goods: interdependencies and hybridity. Land Use Policy 104709. https://doi.org/10.1016/j.landusepol.2020.104709.
Blackstock, K.L., Ingram, J., Burton, R., Brown, K.M., Slee, B., 2010. Understanding and influencing behaviour change by farmers to improve water quality. Sci. Total Environ. 408 (23), 5631–5638. https://doi.org/10.1016/j.scitotenv.2009.04.029.
Bohnet, I.C., 2014. Lessons learned from public participation in water quality improvement planning: a study from Australia. Soc. Nat. Resour. 28 (2), 180–196. https://doi.org/10.1080/08941920.2014.941446.
Botha, N., Coutts, J., Roth, H., 2008. The role of agricultural consultants in New Zealand in environmental extension. J. Agric. Educ. Ext. 14 (2), 125–138. https://doi.org/10.1080/13892240802019147.
Bouma, J., Verbraak, M., Dietz, F., Brouwer, R., 2019. Policy mix: mess or merit? J. Environ. Econ. Policy 8 (1), 32–47. https://doi.org/10.1080/21606544.2018.1494636.
Braithwaite, J., 1982. Enforced self-regulation: a new strategy for corporate crime control. Michigan Law Rev. 80 (7), 1466–1507. https://www.jstor.org/stable/1288556.
Bréthaut, C., Pflieger, G., 2015. The shifting territorialities of the Rhone River's transboundary governance: a historical analysis of the evolution of the functions, uses and spatiality of river basin governance. Reg. Environ. Change 15, 549–558. https://doi.org/10.1007/s10113-013-0541-4.
Brodie, J., Grech, A., Pressey, B., Day, J., Dale, A., Morrison, T., Wenger, A., 2019. The future of the Great Barrier Reef: the water quality imperative. In: Coasts and Estuaries. Elsevier, pp. 477–499.
Brodie, J., Lewis, S., Collier, C.J., Wooldridge, S., Bainbridge, Z.T., Waterhouse, J., Fabricius, K., 2017. Setting ecologically relevant targets for river pollutant loads to meet marine water quality requirements for the Great Barrier Reef, Australia: a preliminary methodology and analysis. Ocean Coast. Manag. 143, 136–147. https://doi.org/10.1016/j.ocecoaman.2016.09.028.
Brodie, J., Pearson, R.G., 2016. Ecosystem health of the Great Barrier Reef: time for effective management action based on evidence. Estuar. Coast. Shelf Sci. 183 (B), 438–451. https://doi.org/10.1016/j.ecss.2016.05.008.
Brodie, J., Waterhouse, J., 2012. A critical review of environmental management of the 'not so Great' Barrier Reef. Estuar. Coast. Shelf Sci. 104–105 (April), 1–22. https://doi.org/10.1016/j.ecss.2012.03.012.
Bromley, D.W., 1989. Economic Interests and Institutions: The Conceptual Foundations of Public Policy. Blackwell Pub.
Bromley, D.W., 1991. Environment and Economy: Property Rights and Public Policy. Basil Blackwell Ltd.
Brown, M., 2017. Grazing BMP - encouraging management changes in the grazing business. Rural Ext. Innov. Syst. J. 13 (2), 131–134.
Busetti, S., Capano, G., 2020. First-and second-order mechanisms: a case study application. In: Capano, G., Howlett, M. (Eds.), A Modern Guide to Public Policy. Edward Elgar Publishing, pp. 131–151.
Campbell, A., 2016. Two steps forward, one back. the ongoing failure to capture synergies in natural resource management (Australia). In: Esau, C., Young, M. (Eds.), Transformational Change in Environmental and Natural Resource Management. Guidelines for Policy Excellence. Taylor and Francis, pp. 80–94.
Capano, G., 2020. Studying public policy: a mechanistic perspective. In: Capano, G., Howlett, M. (Eds.), A Modern Guide to Public Policy. Edward Elgar Publishing, pp. 112–130.
Capano, G., Howlett, M., 2019. Causal logics and mechanisms in policy design: how and why adopting a mechanistic perspective can improve policy design. Public Policy

and Admin. 36 (2), 141–162. https://doi.org/10.1177/0952076719827068, 0952076719827068.
Capano, G., Howlett, M., 2020. The knowns and unknowns of policy instrument analysis: policy tools and the current research agenda on policy mixes. SAGE Open 10 (1), 1–13. https://doi.org/10.1177/2158244019900568.
Carroll, C., Waters, D., Vardy, S., Silburn, D.M., Attard, S., Thorburn, P.J., Wilson, B., 2012. A paddock to reef monitoring and modelling framework for the Great Barrier Reef: paddock and catchment component. Mar. Pollut. Bull. 65 (4–9), 136–149. https://doi.org/10.1016/j.marpolbul.2011.11.022.
Carvalho, L., Mackay, E.B., Cardoso, A.C., Baattrup-Pedersen, A., Birk, S., Blackstock, K. L., Ferreira, M.T., 2019. Protecting and restoring Europe's waters: an analysis of the future development needs of the Water Framework Directive. Sci. Total Environ. 658, 1228–1238. https://doi.org/10.1016/j.scitotenv.2018.12.255.
Challen, R., 2000. Institutions, transaction costs, and environmental policy: institutional reform for water resources. Edward Elgar Publishing.
Coggan, A., Thorburn, P., Fielke, S., Hay, R., Smart, J.C.R., 2021. Motivators and barriers to adoption of improved land management practices. a focus on practice change for water quality improvement in Great Barrier Reef catchments. Mar. Pollut. Bull. 170, 112628 https://doi.org/10.1016/j.marpolbul.2021.112628.
Coglianese, C., Lazer, D., 2003. Management-based regulation: prescribing private management to achieve public goals. Law Soc. Rev. 37 (4), 691–730. https://doi.org/10.1046/j.0023-9216.2003.03703001.x.
Colebatch, H.K., 2014. Making sense of governance. Policy Soc. 33 (4), 307–316. https://doi.org/10.1016/j.polsoc.2014.10.001.
Commons, J.R., 1924. Legal Foundations of Capitalism, vol. 31. Transaction Publishers.
Commonwealth of Australia, 2021. Reef Trust Projects. Department of Agriculture, Water and the Environment. https://www.environment.gov.au/marine/gbr/reef-trust/projects.
Coutts, J., Long, P., Murray-Prior, R., 2017a. Education & Extension in Reef Catchments – Extension Approaches and Methods. Background Paper. Coutts J&R.
Coutts, J., Murray-Prior, R., Long, P., Coutts, B., 2017b. Practice Change, Education and Extension in Reef Catchments Project. Coutts J&R.
Craik, W., 1992. The Great Barrier Reef Marine Park: its establishment, development and current status. Mar. Pollut. Bull. 25 (5–8), 122–133. https://doi.org/10.1016/0025-326X(92)90215-R.
Dale, A.P., Vella, K., Gooch, M., Potts, R., Pressey, R.L., Brodie, J., Eberhard, R., 2017. Avoiding implementation failure in catchment landscapes: a case study in governance of the Great Barrier Reef. Environ. Manag. 1–12 https://doi.org/10.1007/s00267-017-0932-2.
Dalkin, S.M., Greenhalgh, J., Jones, D., Cunningham, B., Lhussier, M., 2015. What's in a mechanism? Development of a key concept in realist evaluation. Implement. Sci. 10 (1), 49. https://doi.org/10.1186/s13012-015-0237-x.
Davis, A.M., 2019. Engaging with farmers and demonstrating water quality outcomes to create confidence in on- farm decision-making ("Project 25"). In: Report to the National Environmental Science Program.
Day, J.C., Dobbs, K., 2013. Effective governance of a large and complex cross-jurisdictional marine protected area: Australia's Great Barrier Reef. Mar. Policy 41, 14–24. https://doi.org/10.1016/j.marpol.2012.12.020.
de Oca Munguia, O.M., Llewellyn, R., 2020. The adopters versus the technology: which matters more when predicting or explaining adoption? Appl. Econ. Perspect. Policy 42 (1), 80–91. https://doi.org/10.1002/aepp.13007.
de Oca Munguia, O.M., Pannell, D.J., Llewellyn, R., Stahlmann-Brown, P., 2021. Adoption pathway analysis: representing the dynamics and diversity of adoption for agricultural practices. Agric. Syst. 191, 103173 https://doi.org/10.1016/j.agsy.2021.103173.
De'ath, G., Fabricius, K., Sweatman, H., Puotinen, M., 2012. The 27–year decline of coral cover on the Great Barrier Reef and its causes. Proc. Natl. Acad. Sci. 109 (44), 17995–17999. https://doi.org/10.1073/pnas.1208909109.
Deane, F., Wilson, C., Rowlings, D., Webb, J., Mitchell, E., Hamman, E., Grace, P., 2018. Sugarcane farming and the Great Barrier Reef: the role of a principled approach to change. Land Use Policy 78, 691–698. https://doi.org/10.1016/j.landusepol.2018.07.026.
Dengler, M., 2007. Spaces of power for action: governance of the Everglades restudy process (1992–2000). Polit. Geogr. 26 (4), 423–454. https://doi.org/10.1016/j.polgeo.2006.12.004.
Doole, G.J., 2012. Cost-effective policies for improving water quality by reducing nitrate emissions from diverse dairy farms: an abatement–cost perspective. Agric. Water Manag. 104, 10–20. https://doi.org/10.1016/j.agwat.2011.11.007.
Dunlop, C.A., Radaelli, C.M., 2020. The lessons of policy learning: types, triggers, hindrances and pathologies. In: Capano, G., Howlett, M. (Eds.), A Modern Guide to Public Policy. Edward Elgar Publishing.
Duttterer, A.D., Margerum, R.D., 2014. The limitations of policy-level collaboration: A meta-analysis of CALFED. Soc. Nat. Resour. 28 (1), 21–37. https://doi.org/10.1080/08941920.2014.945054.
Eastwood, C., Klerkx, L., Nettle, R., 2017. Dynamics and distribution of public and private research and extension roles for technological innovation and diffusion: case studies of the implementation and adaptation of precision farming technologies. J. Rural. Stud. 49, 1–12. https://doi.org/10.1016/j.jrurstud.2016.11.008.
Eberhard, R., 2018. The metagovernance of Australian water policy: practices, rationales and outcomes. Queensland University of Technology, Brisbane.
Eberhard, R., Brodie, J., Waterhouse, J., 2017. Managing water quality for the Great Barrier Reef. In: Hart, B., Doolan, J. (Eds.), Decision Making in Water Resources Policy and Management: An Australian Perspective. Elsevier, pp. 265–289. https://doi.org/10.1016/B978-0-12-810523-8.00016-1.
Environmental Protection Act, 1994. Environmental Protection Act (Qld).
Environmental Protection (Great Barrier Reef Protection Measures) and Other Legislation Amendment Act, 2019. Environmental Protection (Great Barrier Reef Protection Measures) and Other Legislation Amendment Act (Qld).
Ewert, B., Loer, K., 2020. Beyond nudge: advancing behavioural public policies. Policy Polit. 49 (1), 3–23. https://doi.org/10.1332/030557320X15987279194319.
Farquharson, R., Darbas, T., Graham, S., Reeve, I., 2008. Co-regulation and cotton: governance of natural resource management in the Australian cotton industry. Australas. J. Nat. Resour. Law Policy 12 (2), 87.
Fielke, S., Taylor, B., Jakku, E., 2020. Digitalisation of agricultural knowledge and advice networks: a state-of-the-art review. Agric. Syst. 180, 102763 https://doi.org/10.1016/j.agsy.2019.102763.
Game, E.T., Bremer, L.L., Calvache, A., Moreno, P.H., Vargas, A., Rivera, B., Rodriguez, L. M., 2018. Fuzzy models to inform social and environmental indicator selection for conservation impact monitoring. Conserv. Lett. 11 (1), e12338 https://doi.org/10.1111/conl.12338.
Gardner, A., Waschka, M., 2012. Using regulation to tackle the challenge of diffuse water pollution and its impact on the Great Barrier Reef. Tthe challenge of managing diffuse source pollution from agriculture: GBR case study and Queensland's reef protection legislation: an analysis. Australas. J. Nat. Resour. Law Policy 15 (2), 109.
German, R.N., Thompson, C.E., Benton, T.G., 2017. Relationships among multiple aspects of agriculture's environmental impact and productivity: a meta-analysis to guide sustainable agriculture. Biol. Rev. 92 (2), 716–738. https://doi.org/10.1111/brv.12251.
Grant, M.J., Booth, A., 2009. A typology of reviews: an analysis of 14 review types and associated methodologies. Health Inform. Libr. J. 26 (2), 91–108. https://doi.org/10.1111/j.1471-1842.2009.00848.x.
Great Barrier Reef Foundation, 2021. Water quality. Retrieved 5 July from. Great Barrier Reef Foundation. https://www.barrierreef.org/what-we-do/reef-trust-partnership/water-quality-improvement.
Great Barrier Reef Marine Park Authority, 2019. Great Barrier Reef Outlook Report 2019. Great Barrier Reef Marine Park Authority. http://elibrary.gbrmpa.gov.au/jspui/handle/11017/3474.
Great Barrier Reef Protection Amendment Act, 2009. Great Barrier Reef Protection Amendment Act (Qld).
Great Barrier Reef Water Science Taskforce, 2016. Great Barrier Reef Water Science Taskforce Final Report. May 2016. Clean Water for a Healthy Reef. Q. Government.
Greiner, R., 2015. Ex-post evaluation of an environmental auction: Legacy of the 2008 Lower Burdekin Water Quality Tender. In: Report to the National Environmental Science Program.
Guenther, J., Benveniste, T., Redman-MacLaren, M., Mander, D., McCalman, J., O'Bryan, M., Stewart, R., 2020. Thinking with theory as a policy evaluation tool: the case of boarding schools for remote First Nations students. Eval. J. Australas. 20 (1), 34–52. https://doi.org/10.1177/1035719X20905056.
Guerrin, J., Bouleau, G., Grelot, F., 2014. "'Functional fit"' versus "'politics of scale"' in the governance of floodplain retention capacity. Reg. Environ. Change 15, 2405–2414. https://doi.org/10.1007/s10113-013-0541-4.
Gunningham, N., 2004. Cotton, health and environment: a case study of self-regulation. Australas. J. Nat. Resour. Law Policy 9 (2), 189.
Gunningham, N., Sinclair, D., 2004. Curbing non-point pollution: lessons for the Swan-Canning. Environ. Plan. Law J. 21, 181–199.
Gunningham, N., Sinclair, D., 2005. Policy instrument choice and diffuse source pollution. J. Environ. Law 17 (1), 51–81. https://doi.org/10.1093/envlaw/eqi003.
Hamman, E., Deane, F., 2018. he Control of Nutrient Run-Off from Agricultural Areas: Insights into Governance from Australia's Sugarcane Industry and the Great Barrier Reef. Transn. Environ. Law 7 (3), 451–468. https://doi.org/10.1017/S2047102518000018.
Hasle, P., Limborg, H.J., Nielsen, K.T., 2014. Working environment interventions – bridging the gap between policy instruments and practice. Saf. Sci. 68, 73–80. https://doi.org/10.1016/j.ssci.2014.02.014.
Hay, R., Eagle, L., Saleem, M.A., 2019. Social marketing's role in improving water quality on the Great Barrier Reef. Asia Pac. J. Mark. Logist. 31 (5), 1308–1343. https://doi.org/10.1108/APJML-08-2018-0318 doi:0.1108/APJML-08-2018-0318.
Heikkila, T., Gerlak, A.K., 2016. Investigating collaborative processes over time: a 10-year study of the South Florida Ecosystem Restoration Task Force. Am. Rev. Public Admin. 46 (2), 180–200. https://doi.org/10.1177/0275074014544196.
Henstra, D., Thistlethwaite, J., Dordi, T., 2020. Evaluating the suitability of policy instruments for urban flood risk reduction. Local Environ. 25 (2), 101–113. https://doi.org/10.1080/13549839.2019.1710485.
Hepburn, L., Nash, M., 2019. Prioritisation in practice: targeted extension in Great Barrier reef water quality improvement programs. Rural Ext. Innov. Syst. J. 15 (1), 86.
Hill, R., Davies, J., Bohnet, I., Robinson, C., Maclean, K., Pert, P., 2015. Collaboration mobilises institutions with scale-dependent comparative advantage in landscape-scale biodiversity conservation. Environ. Sci. Pol. 51, 267–277. https://doi.org/10.1016/j.envsci.2015.04.014.
Howlett, M., 2019. Designing Public Policies: Principles and Instruments. Routledge.
Howlett, M., 2020a. Dealing with the dark side of policy-making: managing behavioural risk and volatility in policy designs. J. Comp. Policy Anal. Res. Pract. 22 (6), 612–625. https://doi.org/10.1080/13876988.2020.1788942.
Howlett, M., 2020b. Understanding policy target behaviour: compliance problems and the limitations of the utility paradigm. In: Capano, G., Howlett, M. (Eds.), A Modern Guide to Public Policy. Edward Elgar Publishing, pp. 152–163.
Howlett, M., Ramesh, M., Capano, G., 2020. Policy-makers, policy-takers and policy tools: dealing with behavioural issues in policy design. J. Comp. Policy Anal. Res. Pract. 22 (6), 487–497. https://doi.org/10.1080/13876988.2020.1774367.

Hughes, T.P., Kerry, J.T., Álvarez-Noriega, M., Álvarez-Romero, J.G., Anderson, K.D., Baird, A.H., Berkelmans, R., 2017. Global warming and recurrent mass bleaching of corals. Nature 543 (7645), 373–377. https://doi.org/10.1038/nature21707.

Jacobs, 2014. Institutional and Legal Mechanisms That Provide Coordinated Planning, Protection and Management of the Great Barrier Reef World Heritage Area. Jacobs, Brisbane.

Kennedy, H., 2019. AgForce dumps best management practice data. Queensland Country Life. https://www.queenslandcountrylife.com.au/story/6101483/bmp-data-deleted-over-privacy-fears/.

King, J., Alexander, F., Brodie, J., 2013. Regulation of pesticides in Australia: the Great Barrier Reef as a case study for evaluating effectiveness. Agric. Ecosyst. Environ. 180, 54–67. https://doi.org/10.1016/j.agee.2012.07.001.

Kiss, L., Fotheringhame, D., Mak, J., McAlpine, A., Zimmerman, C., 2020. The use of Bayesian networks for realist evaluation of complex interventions: evidence for prevention of human trafficking. J. Comput. Soc. Sci. 1–24. https://doi.org/10.1007/s42001-020-00067-8.

Klerkx, L., 2020. Advisory services and transformation, plurality and disruption of agriculture and food systems: towards a new research agenda for agricultural education and extension studies. J. Agric. Educ. Ext. 26 (2), 131–140. https://doi.org/10.1080/1389224X.2020.1738046.

Klijn, E.-H., Koppenjan, J.F.M., 2007. Governing policy networks. In: Morçöl, G. (Ed.), Handbook of Decision Making. CRC Press, pp. 169–188.

Kroon, F.J., Robinson, C.J., Dale, A., 2009. Integrating knowledge to inform water quality planning in the Tully-Murray basin, Australia. Mar. Freshw. Res. 60 (11), 1183–1188. https://doi.org/10.1071/MF08349.

Kroon, F.J., Schaffelke, B., Bartley, R., 2014. Informing policy to protect coastal coral reefs: insight from a global review of reducing agricultural pollution to coastal ecosystems. Mar. Pollut. Bull. 85 (1), 33–41. https://doi.org/10.1016/j.marpolbul.2014.06.003.

Kroon, F.J., Thorburn, P., Schaffelke, B., Whitten, S., 2016. Towards protecting the Great Barrier Reef from land-based pollution. Glob. Chang. Biol. 22 (6), 1985–2002. https://doi.org/10.1111/gcb.13262.

Kuehne, G., Llewellyn, R., Pannell, D.J., Wilkinson, R., Dolling, P., Ouzman, J., Ewing, M., 2017. Predicting farmer uptake of new agricultural practices: a tool for research, extension and policy. Agric. Syst. 156, 115–125. https://doi.org/10.1016/j.agsy.2017.06.007.

Lane, M.B., Robinson, C.J., 2009. Institutional complexity and environmental management: the challenge of integration and the promise of large-scale collaboration. Aust. J. Environ. Manag. (March), 27–35. https://doi.org/10.1080/14486563.2009.9725213.

Liu, S., Ryu, D., Western, A., Webb, A., Lintern, A., Waters, D., Thomson, B., 2017. Modelling the impact of land use and catchment characteristics on stream water quality using a Bayesian hierarchical modelling approach in the Great Barrier Reef catchments. In: 22nd International Congress on Modelling and Simulation, Hobart, Australia.

Liu, T., Bruins, R.J., Heberling, M.T., 2018. Factors influencing farmers' adoption of best management practices: A review and synthesis. Sustainability 10 (2), 432. https://doi.org/10.3390/su10020432.

Lloyd Consulting, 2011. Reef Water Quality Protection Plan Audit Report 2010. Lloyd Consulting, Brisbane.

MacNeil, M.A., Mellin, C., Matthews, S., Wolff, N.H., McClanahan, T.R., Devlin, M., Graham, N.A., 2019. Water quality mediates resilience on the Great Barrier Reef. Nat. Ecol. Evol. 3 (4), 620–627. https://doi.org/10.1038/s41559-019-0832-3.

May, P.J., 2004. Compliance motivations: affirmative and negative bases. Law Soc. Rev. 38 (1), 41–68. https://doi.org/10.1111/j.0023-9216.2004.03801002.x.

McGrath, C., 2010. Does Environmental Law Work?: How to Evaluate the Effectiveness of an Environmental Legal System. Lambert Academic Publishing.

McKenzie-Mohr, D., Schultz, P.W., 2014. Choosing effective behavior change tools. Soc. Mark. Q. 20 (1), 35–46. https://doi.org/10.1177/1524500413519257.

Michie, S., West, R., Sheals, K., Godinho, C.A., 2018. Evaluating the effectiveness of behavior change techniques in health-related behavior: a scoping review of methods used. Transl. Behav. Med. 8 (2), 212–224. https://doi.org/10.1093/tbm/ibx019.

Mickwitz, P., 2003. A framework for evaluating environmental policy instruments: context and key concepts. Evaluation 9 (4), 415–436. https://doi.org/10.1177/1356389003094004.

Milner-Gulland, E., Shea, K., 2017. Embracing uncertainty in applied ecology. J. Appl. Ecol. 54 (6), 2063. https://doi.org/10.1111/1365-2664.12887.

Morrison, T., 2017. The Great Barrier Reef's safety net is becoming more complex but less effective. Aust. Environ. Law Dig. 4 (1), 12.

Morrison, T.H., 2017. Evolving polycentric governance of the Great Barrier Reef. Proc. Natl. Acad. Sci. 114 (15), E3013–E3021. https://doi.org/10.1073/pnas.1620830114.

Nelson, R., 2010. Regulating nonpoint source pollution in the US: a regulatory theory approach to lessons and research paths for Australia. UW Austl. L. Rev. 35, 340.

Norton, G.W., Alwang, J., 2020. Changes in agricultural extension and implications for farmer adoption of new practices. Appl. Econ. Perspect. Policy 42 (1), 8–20.

Olejniczak, K., Sliwowski, P., Leeuw, F., 2020. Comparing behavioral assumptions of policy tools: framework for policy designers. J. Comp. Policy Anal. Res. Pract. 22 (6), 498–520. https://doi.org/10.1080/13876988.2020.1808465.

Olmstead, S.M., 2010. The economics of water quality. Rev. Environ. Econ. Policy 4 (1), 44–62. https://doi.org/10.1093/reep/rep016.

O'Mahoney, J., Simes, R., Redhill, D., Heaton, K., Atkinson, C., Hayward, E., Nguyen, M., 2017. At What Price? The Economic, Social and Icon Value of the Great Barrier Reef. Deloitte Access Economics.

Osborn, D., Datta, A., 2006. Institutional and policy cocktails for protecting coastal and marine environments from land-based sources of pollution. Ocean Coast. Manag. 49 (9–10), 576–596. https://doi.org/10.1016/j.ocecoaman.2006.06.020.

Pannell, D., Zilberman, D., 2020. Understanding adoption of innovations and behavior change to improve agricultural policy. Appl. Econ. Perspect. Policy 42 (1), 3–7. https://doi.org/10.1002/aepp.13013.

Pannell, D.J., Claassen, R., 2020. The roles of adoption and behavior change in agricultural policy. Appl. Econ. Perspect. Policy 42 (1), 31–41. https://doi.org/10.1002/aepp.13009.

Pannell, D.J., Marshall, G.R., Barr, N., Curtis, A., Vanclay, F., Wilkinson, R., 2006. Understanding and promoting adoption of conservation practices by rural landholders. Aust. J. Exp. Agric. 46 (11), 1407–1424. https://doi.org/10.1071/ea05037.

Pannell, D.J., Roberts, A.M., Park, G., Curatolo, A., Marsh, S., Alexander, J., 2009. INFFER (Investment Framework for Environmental Resources). INFFER Working Paper 0901. http://cyllene.uwa.edu.au/~dpannell/dp0901.htm.

Parker, C., Nielsen, V.L., 2017. Compliance: 14 questions. In: Drahos, P. (Ed.), Regulatory Theory: Foundations and Applications. ANU Press, pp. 217–232.

Parliament of Australia, 2020. Identification of leading practices in ensuring evidence-based regulation of farm practices that impact water quality outcomes in the Great Barrier Reef. https://www.aph.gov.au/Parliamentary_Business/Committees/Senate/Rural_and_Regional_Affairs_and_Transport/GreatBarrierReef.

Pathak, S., Paudel, K.P., Adusumilli, N.C., 2021. Impact of the Federal Conservation Program Participation on Conservation Practice Adoption Intensity in Louisiana, USA. Environ. Manag. 1–16 https://doi.org/10.1007/s00267-021-01477-8.

Pawson, R., 2006. Evidence-based Policy: A Realist Perspective. Sage. https://doi.org/10.4135/9781849209120.n2.

Pawson, R., Tilley, N., 1997. Realistic Evaluation. Sage Publications.

Phillipson, J., Proctor, A., Emery, S.B., Lowe, P., 2016. Performing inter-professional expertise in rural advisory networks. Land Use Policy 54, 321–330. https://doi.org/10.1016/j.landusepol.2016.02.018.

Pickering, J., Hong, J., Hong, D., Kealley, M., 2017. Applying behavioural science to the Queensland sugar cane industry and its relationship to the Great Barrier Reef. Rural Ext. Innov. Syst. J. 13 (2), 1.

Pickering, J., Hong, J., Stower, R., Hong, D., Kealley, M., 2018. Using psychology to understand practice change among sugar cane growers. Rural Ext. Innov. Syst. J. 14 (1), 62–72.

Prager, K., Labarthe, P., Caggiano, M., Lorenzo-Arribas, A., 2016. How does commercialisation impact on the provision of farm advisory services? Evidence from Belgium, Italy, Ireland and the UK. Land Use Policy 52, 329–344. https://doi.org/10.1016/j.landusepol.2015.12.024.

Prokopy, L.S., Floress, K., Arbuckle, J.G., Church, S.P., Eanes, F., Gao, Y., Singh, A.S., 2019. Adoption of agricultural conservation practices in the United States: evidence from 35 years of quantitative literature. J. Soil Water Conserv. 74 (5), 520–534. https://doi.org/10.2489/jswc.74.5.520.

Ranjan, P., Church, S.P., Floress, K., Prokopy, L.S., 2019. Synthesizing conservation motivations and barriers: what have we learned from qualitative studies of farmers' behaviors in the United States? Soc. Nat. Resour. 32 (11), 1171–1199. https://doi.org/10.1080/08941920.2019.1648710.

Raymond, B., McInnes, J., Dambacher, J.M., Way, S., Bergstrom, D.M., 2011. Qualitative modelling of invasive species eradication on subantarctic Macquarie Island. J. Appl. Ecol. 48 (1), 181–191. https://doi.org/10.1111/j.1365-2664.2010.01916.x.

Rees, J., 1997. Development of communitarian regulation in the chemical industry. Law Policy 19 (4), 477–528. https://doi.org/10.1111/1467-9930.00036.

Rhodes, R.A., 2012. Waves of governance. In: Levi-Faur, D. (Ed.), Oxford Handbook of Governance. Oxford University Press, pp. 33–48.

Ribaudo, M., Shortle, J., 2019. Reflections on 40 years of applied economics research on agriculture and water quality. J. Agric. Resour. Econ. 48 (3), 519–530 (doi:0.1017/age.2019.32).

Roberts, A., Eberhard, R., Dickson, M., 2020. Queensland Reef Water Quality Program 2020 Evaluation Final Report. Natural Decisions.

Roberts, A., Eberhard, R., Dickson, M., Park, G., 2018. Queensland Reef Water Quality Program 2018 Evaluation. Natural Decisions.

Roberts, A., Eberhard, R., Dickson, M., Park, G., Waterhouse, J., 2018. Queensland Reef Water Quality Program Evaluation Framework. Natural Decisions.

Robinson, C.J., Eberhard, R., Wallington, T., Lane, M., 2010. Using knowledge to make collaborative policy-level decisions in Australia's Great Barrier Reef. CSIRO.

Rolfe, J., Harvey, S., 2017. Heterogeneity in practice adoption to reduce water quality impacts from sugarcane production in Queensland. J. Rural. Stud. 54, 276–287. https://doi.org/10.1016/j.jrurstud.2017.06.021.

Rolfe, J., Windle, J., 2011a. Comparing a best management practice scorecard with an auction metric to select proposals in a water quality tender. Land Use Policy 28 (1), 175–184. https://doi.org/10.1016/j.landusepol.2010.05.011.

Rolfe, J., Windle, J., 2011b. Using auction mechanisms to reveal costs for water quality improvements in Great Barrier Reef catchments in Australia. Agric. Water Manag. 98 (4), 493–501. https://doi.org/10.1016/j.agwat.2010.09.007.

Rolfe, J., Windle, J., 2016. Benchmarking costs of improving agricultural water management in GBR catchments. In: Report to the National Environmental Science Programme, Reef and Rainforest Research Centre Limited, Cairns.

Rolfe, J., Windle, J., McCosker, K., Northey, A., 2018a. Assessing cost-effectiveness when environmental benefits are bundled: agricultural water management in Great Barrier Reef catchments. Aust. J. Agric. Resour. Econ. 62 (3), 373–393. https://doi.org/10.1111/1467-8489.12259.

Rolfe, J., Windle, J., McCosker, K., Northey, A., 2018b. Assessing cost-effectiveness when environmental benefits are bundled: agricultural water management in Great Barrier

Reef catchments. Aust. J. Agric. Resour. Econ. 62 (3), 373–393. https://doi.org/10.1111/1467-8489.12259.

Rolfe, J., Windle, J., McCosker, K., Northey, A., 2018c. Assessing cost-effectiveness when environmental benefits are bundled: agricultural water management in Great Barrier Reef catchments. Aust. J. Agric. Resour. Econ. https://doi.org/10.1111/1467-8489.12259.

Ronchi, S., Salata, S., Arcidiacono, A., Piroli, E., Montanarella, L., 2019. Policy instruments for soil protection among the EU member states: a comparative analysis. Land Use Policy 82, 763–780. https://doi.org/10.1016/j.landusepol.2019.01.017.

Rosas, F., Babcock, B.A., Hayes, D.J., 2015. Nitrous oxide emission reductions from cutting excessive nitrogen fertilizer applications. Clim. Chang. 132 (2), 353–367. https://doi.org/10.1007/s10584-015-1426-y.

Rouse, A., Davenport, C., 2017. Project Catalyst: an innovation project for cane growers in the Great Barrier Reef catchment. Rural Extension and Innovation Systems Journal 13 (2), 167.

Royle, A., Di Bella, L., 2017. Targeted sugarcane grower extension improves reef water quality. Rural Ext. Innov. Syst. J. 13 (2), 187.

Schlager, E., Ostrom, E., 1992. Property-rights regimes and natural resources: a conceptual analysis. Land Econ. 249–262. https://doi.org/10.2307/3146375.

Scholz, J.T., 1984. Cooperation, deterrence, and the ecology of regulatory enforcement. Law Soc. Rev. 179–224. https://www.jstor.org/stable/3053402.

Shellberg, J.G., 2021. Agricultural development risks increasing gully erosion and cumulative sediment yields from headwater streams in Great Barrier Reef catchments. Land Degrad. Dev. 32 (3), 1555–1569. https://doi.org/10.1002/ldr.3807.

Shenton, W., Hart, B.T., Brodie, J., 2010. A Bayesian network model linking nutrient management actions in the Tully catchment (northern Queensland) with Great Barrier Reef condition. Mar. Freshw. Res. 61 (5), 587–595. https://doi.org/10.1071/MF09093.

Shortle, J., Horan, R.D., 2013. Policy instruments for water quality protection. Ann. Rev. Resour. Econ. 5 (1), 111–138. https://doi.org/10.1146/annurev-resource-091912-151903.

Shortle, J., Ollikainen, M., Iho, A., 2021. Water Quality and Agriculture. Economics and Policy for Nonpoint Source Water Pollution. Palgrave Macmillan. https://doi.org/10.1007/978-3-030-47087-6 (in press).

Simmons, B.A., Wilson, K.A., Dean, A.J., 2020. Landholder typologies illuminate pathways for social change in a deforestation hotspot. J. Environ. Manag. 254, 109777 https://doi.org/10.1016/j.jenvman.2019.109777.

Simmons A., B., Wilson A., K., Marcos-Martinez, R., Bryan A., B., Holland, O., Law A., E., 2018. Effectiveness of regulatory policy in curbing deforestation in a biodiversity hotspot. Environmental Research Letters 13 (12), 124003. https://doi.org/10.1088/1748-9326/aae7f9.

Sinclair, D., 1997. Self-regulation versus command and control? Beyond false dichotomies. Law & Policy 19 (4), 529–559. https://doi.org/10.1111/1467-9930.00037.

Smart, J.B., Hasan, S., Volders, A., Curwen, G., Fleming, C., Burford, M., 2016. A tradable permit scheme for cost-effective reduction of nitrogen runoff in the sugarcane catchments of the Great Barrier Reef. In: Report to the National Environmental Science Programme.

Smee, B., 2019a. AgForce backs calls for review of consensus science on Great Barrier Reef. The Guardian. https://www.theguardian.com/environment/2019/sep/02/agforce-backs-calls-for-review-of-consensus-science-on-great-barrier-reef.

Smee, B., 2019b. AgForce deletes decade's worth of data from government-funded barrier reef program. The Guardian. https://www.theguardian.com/australia-news/2019/may/02/agforce-deletes-decades-worth-of-data-from-government-funded-barrier-reef-program.

Smee, B., 2019c. Cane growers support front group working to undermine Great Barrier Reef science. The Guardian. https://www.theguardian.com/environment/2019/aug/23/sugarcane-farmers-support-group-working-to-undermine-great-barrier-reef-science.

Smee, B., 2019d. Canegrowers given reef foundation grant while campaigning against pollution regulation. The Guardian. https://www.theguardian.com/australia-news/2019/aug/17/canegrowers-given-reef-foundation-grant-while-campaigning-against-pollution-regulation.

Spicer, E.A., Swaffield, S., Moore, K., 2021. Agricultural land use management responses to a cap and trade regime for water quality in Lake Taupo catchment, New Zealand. Land Use Policy 102, 105200. https://doi.org/10.1016/j.landusepol.2020.105200.

Star, M., Rolfe, J., Barbi, E., 2019. Do outcome or input risks limit adoption of environmental projects: rehabilitating gullies in Great Barrier Reef catchments. Ecol. Econ. 161, 73–82. https://doi.org/10.1016/j.ecolecon.2019.03.005.

Star, M., Rolfe, J., Donaghy, P., Beutel, T., Whish, G., Abbott, B., 2013. Targeting resource investments to achieve sediment reduction and improved Great Barrier Reef health. Agric. Ecosyst. Environ. 180, 148–156. https://doi.org/10.1016/j.agee.2012.03.016.

Star, M., Rolfe, J., McCosker, K., Smith, R., Ellis, R., Waters, D., Waterhouse, J., 2018. Targeting for pollutant reductions in the Great Barrier Reef river catchments. Environ. Sci. Pol. 89, 365–377. https://doi.org/10.1016/j.envsci.2018.09.005.

State of Queensland, 2018. Queensland Reef Water Quality Program. Five-year Investment Plan. 2017–18 to 2021–2022. https://www.qld.gov.au/_data/assets/pdf_file/0032/68873/qld-reef-water-5year-invest-plan.pdf.

State of Queensland, 2019a. Agricultural ERA standard. Sugarcane cultivation in the Great Barrier Reef catchment. https://www.qld.gov.au/_data/assets/pdf_file/0017/113147/sugarcane-era-standard.pdf.

State of Queensland, 2019b. Department of Environment and Science. Enforcement Guidelines. https://environment.des.qld.gov.au/_data/assets/pdf_file/0030/86619/enforcement-guidelines.pdf.

State of Queensland, 2019c. Guide to Better Regulation. https://s3.treasury.qld.gov.au/files/guide-to-better-regulation.pdf.

State of Queensland, 2020. Compliance. Retrieved 13 January 2021 from. Queensland Government. https://www.qld.gov.au/environment/agriculture/sustainable-farming/reef/reef-regulations/producers/compliance.

State of Queensland and Commonwealth of Australia, 2003. Reef Water Quality Protection Plan: For Catchments Adjacent to the Great Barrier Reef World Heritage. October 2003.

State of Queensland and Commonwealth of Australia, 2009. Reef Water Quality Protection Plan: For the Great Barrier Reef World Heritage Area and Adjacent Catchments.

State of Queensland and Commonwealth of Australia, 2013. Reef Water Quality Protection Plan 2013: Securing the Health and Resilience of the Great Barrier Reef World Heritage Area and Adjacent Catchments.

State of Queensland and Commonwealth of Australia, 2018a. Reef 2050 Water Quality Improvement Plan 2017–2022.

State of Queensland and Commonwealth of Australia, 2018b. Reef 2050 Water Quality Improvement Plan Investments.

State of Queensland and Commonwealth of Australia, 2020a. Methods. In: Reef Water Quality Report Card 2019.

State of Queensland and Commonwealth of Australia, 2020b. Results. Reef Water Quality Report Card 2019. Retrieved 29 June 2021 from. Queensland Government. https://www.reefplan.qld.gov.au/tracking-progress/reef-report-card/2019.

Strassheim, H., 2021. Behavioural mechanisms and public policy design: preventing failures in behavioural public policy. Pub. Policy Adm. 36 (2), 187–204. https://doi.org/10.1177/0952076719827062.

Sutinen, J.G., Kuperan, K., 1999. A socio-economic theory of regulatory compliance. Int. J. Soc. Econ. 26 (1/2/3), 174–193. https://doi.org/10.1108/03068299910229569.

Tan, P.-L., Humphries, F., 2018. Adaptive or aspirational? Governance of diffuse water pollution affecting Australia's Great Barrier Reef. Water Int. 43 (3), 361–384. https://doi.org/10.1080/02508060.2018.1446617.

Taylor, B., Lawrence, G.A., 2012. Agri-political organisations in environmental governance: recalcitrant participants or active partners? J. Environ. Policy Plan. 14 (4), 337–359. https://doi.org/10.1080/1523908X.2012.714565.

Taylor, B., van Grieken, M., 2015. Local institutions and farmer participation in agri-environmental schemes. J. Rural. Stud. 37, 10–19. https://doi.org/10.1016/j.jrurstud.2014.11.011.

Taylor, B., Wallington, T., Robinson, C.J., 2010. Uncertainty and ambiguity in environmental governance: water quality in the Great Barrier Reef. In: Measham, T. G., Lockie, S. (Eds.), Risk and Social Theory in Environmental Management. CSIRO Publishing, pp. 161–174.

Taylor, B.M., Eberhard, R., 2020. Practice change, participation and policy settings: a review of social and institutional conditions influencing water quality outcomes in the Great Barrier Reef. Ocean Coast. Manag. 190, 105156 https://doi.org/10.1016/j.ocecoaman.2020.105156.

Tennent, R., Lockie, S., 2013. Vale Landcare: the rise and decline of community-based natural resource management in rural Australia. J. Environ. Plan. Manag. 56 (4), 572–587. https://doi.org/10.1080/09640568.2012.689617.

Thiel, A., Mukhtarov, F., Zikos, D., 2015. Crafting or designing? Science and politics for purposeful institutional change in social-ecological systems. Environ. Sci. Policy (53), 81–86. https://doi.org/10.1016/j.envsci.2015.07.018.

Thorburn, P., Fitch, P., Zhang, Y., Shendryk, Y., Webster, T., Biggs, Jody, Fielke, S., 2019. Helping Farmers Mitigate Nutrient Losses to the Great Barrier Reef Through "Digital Agriculture". Massey University. Occasional report, issue 32.

Ulibari, N., Escobedo Garcia, N., 2020. Comparing complexity in watershed governance: the case of California. Water 12 (3), 766–785. https://doi.org/10.3390/w12030766.

van Grieken, M., Lynam, T., Coggan, A., Whitten, S., Kroon, F., 2013. Cost effectiveness of design-based water quality improvement regulations in the Great Barrier Reef Catchments. Agric. Ecosyst. Environ. 180, 157–165. https://doi.org/10.1016/j.agee.2011.08.010.

van Grieken, M., Poggio, M., Smith, M., Taylor, B., Thorburn, P., Biggs, J., Whitten, S., Faure, C., Boullier, A., 2014. Cost-effectiveness of management activities for water quality improvement in sugarcane farming. Report to the Reef Rescue Water Quality Research & Development Program. Reef and Rainforest Research Centre Limited, Cairns.

van Grieken, M.E., Roebeling, P.C., Bohnet, I.C., Whitten, S.M., Webster, A.J., Poggio, M., Pannell, D., 2019. Adoption of agricultural management for Great Barrier Reef water quality improvement in heterogeneous farming communities. Agric. Syst. 170, 1–8. https://doi.org/10.1016/j.agsy.2018.12.003.

Vargas, M.H.F., Restrepo, D.R., 2019. The instruments of public policy. A transdisciplinary look. Cuad. Adm. (Univ. Valle) 35 (63), 101–113. https://doi.org/10.25100/cdea.v35i63.6893.

Vedung, E., 1998. Policy instruments: typologies and theories. In: Bemelmans-Videc, M. L., Rist, R.C., Vedung, E. (Eds.), Carrots, Sticks and Sermons: Policy Instruments and Their Evaluation. Transaction Publishers, pp. 21–58.

Vella, K., Baresi, U., 2017. Understanding how policy actors improvise and collaborate in the Great Barrier Reef. Coast. Manag. 45 (6), 487–504. https://doi.org/10.1080/08920753.2017.1373453.

Vella, K., Cole-Hawthorne, R., Hardaker, M., 2017. The Value Proposition of Regional Natural Resource Management in Queensland Final Report. Queensland University of Technology.

Vella, K., Dale, A., 2014. An approach for adaptive and integrated agricultural planning to deal with uncertainty in a Great Barrier Reef Catchment. Aust. Plan. 51 (3), 243–259. https://doi.org/10.1080/07293682.2013.837831.

Vella, K., Sipe, N., Dale, A., Taylor, B., 2015. Not learning from the past: adaptive governance challenges for Australian natural resource management. Geogr. Res. 53 (4), 379–392. https://doi.org/10.1111/1745-5871.12115.

Waschka, M., Gardner, A.W., 2016. Diffuse source pollution and water quality law for the Great Barrier Reef Why the reticence to regulate? In: Gray, J., Holley, C., Rayfuse, R. (Eds.), Trans-jurisdictional Water Law and Governance, 1st ed. Routledge, pp. 195–213.

Waterhouse, J., Schaffelke, B., Bartley, R., Eberhard, R., Brodie, J., Star, M., Kroon, F., 2017. 2017 Scientific Consensus Statement: Land Use Impacts on Great Barrier Reef Water Quality and Ecosystem Condition. State of Queensland.

Waters, D.K., Carroll, C., Ellis, R., Hateley, L., McCloskey, G.L., Packett, R., Fentie, B., 2014. Modelling Reductions of Pollutant Loads Due to Improved Management Practices in the Great Barrier Reef Catchments - Whole of GBR Technical Report, vol. 1. http://qldgov.softlinkhosting.com.au/liberty/opac/search.do.

Wauters, E., Mathijs, E., 2014. The adoption of farm level soil conservation practices in developed countries: a meta-analytic review. Int. J. Agric. Resour. Gov. Ecol. 10 (1), 78–102. https://doi.org/10.1504/ijarge.2014.061058.

Waylen, K.A., Blackstock, K.L., Van Hulst, F.J., Damian, C., Horváth, F., Johnson, R.K., Meissner, K., 2019. Policy-driven monitoring and evaluation: does it support adaptive management of socio-ecological systems? Sci. Total Environ. 662, 373–384. https://doi.org/10.1016/j.scitotenv.2018.12.462.

Weber, M., Driessen, P.P., Runhaar, H.A., 2014. Evaluating environmental policy instruments mixes; a methodology illustrated by noise policy in the Netherlands. J. Environ. Plan. Manag. 57 (9), 1381–1397. https://doi.org/10.1080/09640568.2013.808609.

Whitten, S., Langston, A., 2020. Reef Trust Repeated Reverse Auctions: Final Report and Review.

Whitten, S.M., Bennett, J., 2005. Managing Wetlands for Private and Social Good: Theory, Policy and Cases From Australia. Edward Elgar Publishing.

Wilkinson, S., Hairsine, P., Hawdon, A., Austin, J., 2019. Technical Findings and Outcomes From the Reef Trust Gully Erosion Control Program. CSIRO.

Willis, J.W., 2012. General guidelines for qualitative research. In: Willis, J.W. (Ed.), Foundations of Qualitative Research: Interpretive and Critical Approaches. Sage Publications, pp. 185–228. https://doi.org/10.4135/9781452230108.

Willis, M., Nelson, B., Brown, K., 2017. Extension through grazing BMP: an integration of production and natural resource management. Rural Ext. Innov. Syst. J. 13 (2), 156.