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Understanding power, social capital and trust alongside near real-time water quality monitoring and technological development collaboration

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ABSTRACT

We report on qualitative social research conducted with stakeholders in a local agricultural knowledge and advice network associated with a collaborative water quality monitoring project. These farmers, advisors and researchers allude to existing social dynamics, technological developments, and (more general) social evolution which is analysed against a novel analytical framework. This framework considers notions of power, social capital, and trust as related and dynamic, forming the basis of our contribution to knowledge. We then probe the data to understand perceived impacts of the collaborative project and social interaction associated with this research project, which involved cutting edge automated and frequent water quality monitoring that allowed for near real-time access to data visualisation displayed via a bespoke mobile or web 'app' (1622WQ). Our findings indicate that a multi-faceted approach to assessing and intervening based on consideration of multiple social dimensions holds promise in terms of creating conditions that allow for individual and group learning to encourage changes in thinking required to result in improved land management practice.

1. Introduction

There is a need to integrate concepts of power, social capital and trust in order to make sense of how society should invest to alter social systems toward desirable outcomes whilst mitigating inevitable resistance to change (Coggan et al., 2021). This paper bridges the form and functions of three social phenomena – power, social capital, and trust. We then use these concepts to understand how a series of research for impact investments in automated, near real-time water quality monitoring and associated technological development processes influenced a case study agricultural community within the sugarcane industry. Why? Because balancing freshwater quality concerns with social and economic outcomes of land use is a global challenge. For example, research has highlighted the tension between agricultural land use, fertiliser application and environmental implications in New Zealand (Duncan, 2014), Canada (de Loë et al., 2015), the USA (Yoder et al., 2020; Yoder and Chowdhury, 2018), and the Nations surrounding the Baltic Sea (Hasler et al., 2019; Konrad et al., 2019). The coexistence of agricultural industries alongside valuable water resources (tourism generating, for domestic consumption, or as culturally or socially significant sites etc) is often vexing and politically contentious (see, for example Kiem (2013) or O'Keeffe (2009)). Existing social norms and group interactions are critical to determine how farmers perceive the need for, and actions that could or should be undertaken to, improve water quality outcomes influenced by agricultural production (Taylor and Eberhard, 2020).

There are many ways that individual, collective, and institutional characteristics influence decision-making when actions are perceived to have an effect on productivity (Knook et al., 2020). As Knook and Turner (2020) report, via a 'business' logic, farmers in New Zealand and Scotland have been able to absorb environmentally beneficial practice change when it is represented as a requirement to 'maintain a profitable business'. Such a response is argued to need to be supported by stable regulatory changes that provide an extrinsic motivation such that advisory organisations can support such change (Knook and Turner, 2020). Inman et al. (2018) explain that there is a strong argument for trialling such approaches, whereby individual learning is supported and mutually reinforced regarding aiming for water quality improvement within the context of agricultural networks in the United Kingdom. This

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research provides an Australian case whereby the nuance of such roles, individually for farmers and advisors, and at the advisory network (group) and institutional levels, alter over time.

In this paper we focus on changes in thinking and practice at the social collective (group) and institutional levels that might be required to achieve improved land management practice aims. These group and institutional levels have received less attention in the adoption literature than individual values and behaviours (Coggan et al., 2021; Hasan et al., 2021). As many others have discovered, however, such individual values and behaviours are inextricably linked to outcomes in terms of changes in farmer, advisor and researcher behaviour and interaction in agricultural knowledge and advice networks (Engler et al., 2019; Inman et al., 2018; Knook and Turner, 2020; Leeuwis and Aarts, 2021; van Grieken et al., 2019). Here, we draw upon existing work in determining social capital stocks – in form and function – as they relate to flows of trust between individuals and groups they associate with and institutions they may or may not (King et al., 2019). Our case study utilises qualitative interview data from two points in time (2018 and 2020) with actors in the sugarcane farming knowledge and advice network surrounding a collaborative farmer-led water quality monitoring project in the Mulgrave-Russell catchment of the Wet Tropics region of north-eastern Australia (see Fig. 2 in section 3).

We explore the proposition that: *analysing social capital stocks, trust flows and power dynamics throughout transdisciplinary research projects can help plan interventions that increase the likelihood of achieving impact from voluntary changes in farmer behaviour that many improved land management practice initiatives seek.* We also answer three specific research questions relating to this case study that have implications for water quality improvement agendas and environmental management initiatives more generally:

- What are the *power dynamics* (and changes to those dynamics) that need to be considered when aligning terrestrial runoff pollution challenges with agricultural fertiliser management practice?
- How do stocks of *social capital and flows of trust* influence farmer engagement with diffuse water quality monitoring projects over time?
- What are the implications of *considering multiple social characteristics* to improve outcomes from collaborative projects within agricultural knowledge and advice systems?

To answer these questions, we have structured the paper as follows. First, the *literature review and analytical framework* are presented to provide the reader with background on the specific case and the literature this paper directly builds on to understand past (2018) and more recent (2020) power, social capital and trust characteristics and interactions. Second, the primary research *methods and case study context* is presented. The *results* of primary qualitative data analysis then align with the analytical framework previously constructed. The paper proposition is tested, and the three research questions are answered, along with *discussion* points applicable to other agricultural land use and environmental management issues. Finally, the *conclusion* highlights limitations and key findings.

2. Literature review and analytical framework

Power dynamics and forms of social capital stocks and trust flows are a central focus of this paper. These two related concepts have been well studied individually but rarely combined into a single framework to consider the implications of how social dimensions evolve over time. We develop our analytical framework which enables us to highlight the role of social capital, trust, and power dynamics for collaborative water quality monitoring developed in the context of existing social dimensions and interventions over a project lifecycle. The analytical framework also helps us to visualise how individuals were influenced (or not) by changing (or unchanging) social dimensions. The results of our data analysis provide answers to our research questions and help propose reasoning to scale out this social research exploration to other domains/cases of relevance in the future.

2.1. Power dynamics

Existing work to situate and describe dimensions of power – and resources used to exercise power – has helped institutional scholars understand the dynamics of social system interaction in the context of sustainability transitions (Avelino, 2011; Avelino and Rotmans, 2011; Avelino and Wittmayer, 2016; Fuchs and Glaab, 2011; Hoffman, 2013). Such work has been pivotal in framing the likely reactions of select individuals and organisations in response to other individuals and organisations abilities to wield (or yield to) power. Table 1 shows the different forms of power relation and their manifestations – which we have simplified to label 'working separately', 'working together' and 'working for'. In an important step, Ingram (2018) explored the interaction between different levels (referred to as niche and regime) and how such interaction can alter power dynamics as part of societal evolution. Turner et al. (2020) take this further to develop an analytical framework to map alterations in power dynamics over the course of rural or agricultural innovation project interventions. We draw heavily on the analytical framework of Turner et al. (2020) to develop our own (see power dynamics column in Fig. 1), whereby the power relation type and manifestation of power relations result in implications for power dynamics.

2.2. Social capital stocks and trust flows

As well as considering the power dynamics of different individual and organisational settings, the relational component of interactions between individuals and groups is also critical to comprehensively report on the evolution of social dimensions. Useful conceptualisations of social capital as stocks or assets and the types of trust that contribute to such assets (or liabilities) are used here. Since the concept of the *strength of weak ties* was introduced (Granovetter, 1973), and Putnam (1995) brought attention to the concept of 'social capital', significant efforts to further define the concept have followed. Here, we use existing work to segregate forms of social capital by the number and direction of connections labelled: *bonding*, *bridging*, and *linking* social capital (Cofré-Bravo et al., 2019; King et al., 2019; Klerkx and Proctor, 2013; Woodhouse, 2006). Table 2 provides an overview of the number and directionality of connections. The form of social capital (as a stock or asset) has implications for trust as 'currency'. Trust has been referred to as 'relational glue that enables or constrains both formal and informal

Table 1
Power relation typologies and guiding manifestations of power relations (adapted from Avelino and Rotmans (2011)).

Power relation type	Manifestation of power relations		
	Working separately	Working together	Working for
Power 'over'	Independency – A and B have no power over each other	Mutual dependency – A has power over B, but B also has power over A	One-sided dependency – A has power over B, but B does not have power over A
'More or less' power	Co-existence – A exercises more power than B, A and B have independent co-existent goals	Cooperation – A exercises more power than B, but A and B have similar collective goals	Competition – A exercises more power than B, while A and B have mutually exclusive goals
'Different' power	Neutrality – A's and B's different power do not (significantly) affect one another	Synergy – A's and B's different power enable and support one another	Antagonism – A's and B's different power restrict, resist, or disrupt one another

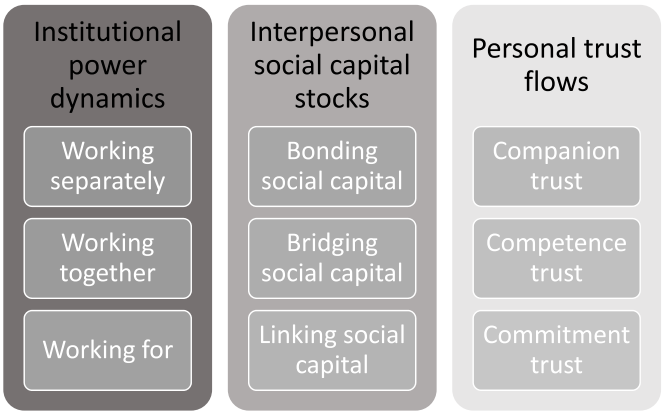

Fig. 1. Analytical framework of power, social capital and trust (adapted from Turner et al. (2020) and King et al. (2019).
Note: darkness indicates the number of individuals that would be required to accept an alteration in each characteristic from 1 to
2 for personal trust flows (light) to many and varied for institutional power dynamics (dark). As such, the hierarchy of relevance moves from left (requiring institutional change) through societal group alterations (middle) and then right (requiring individual changes in perception at the least).

social interactions, knowledge sharing and innovation processes' (King et al., 2019, p. 125).

Fisher (2013) frames trust as foundational to the development of social capital and, like social capital, they suggest trust manifests in different forms. *Companion trust* refers to the long-term development of relations – usually informal in some form, for example via a sporting club, shared school, or casual gathering – that result in a predictability about how a group member might behave in a certain scenario. *Competence trust* refers to reputation as a guide for the more rapid development of trust between individuals or groups of individuals, whereby the individual/groups reputation/s help to determine common expectations about type/s of behaviours likely in both formal and informal settings. Finally, *commitment trust* provides accountability – usually formally via contracts or legal arrangements – that sets the boundaries for an individual/groups commitment/s to one another. Table 2 shows these three forms of trust alongside the most aligned form of social capital. It should be noted that different forms can co-exist with one another and as reported by many, each form of social capital and/or trust can have both positive or negative connotations depending on the social context and perceptions of outcomes sought by the individual/group in question (Heenan, 2010; King et al., 2019; Leung et al., 2013; Michelini, 2013; Portes, 2014; Tregear and Cooper, 2016).

2.2.1. Social capital and trust in collaborative watershed management

It is not immediately obvious that power dynamics, at the institutional level, are related to social capital and trust at the personal and interpersonal levels. Here, we argue that such connection is critical in terms of framing an individual and their group/s response (or lack thereof) to directives. Important work regarding the role of local 'grassroots stakeholders' and the institutional dynamics of collective watershed management highlights that participation in environmental monitoring programmes is linked to social capital (Lubell, 2004). Typically, such interaction has been assessed in terms of a lack of bridging social capital and the over-presence of bonding social capital leading to stagnation in terms of activity engagement that could lead to changes in thinking and then changes in practices (Yoder and Chowdhury, 2018). There is an interaction between the institutional, social group and individual levels in terms of practice change that results in different contextual factors influencing the likelihood of successful water quality monitoring programmes and improved management practices as measured by those imagining the measurement metrics (Coggan et al., 2021; Yoder, 2019). For this reason, novel institutional mechanisms – for example the devolution of responsibility to meet nutrient application limits (Yoder, 2019) – should be considered alongside the existing power dynamics, social capital stocks and trust flows. As Taylor and Van Grieken (2015) explain, importing 'institutions' into agricultural systems needs to be mediated in a manner that allows for a diversity of responses from varying 'subcultures' of farmers, advisors, and organisations themselves.

2.3. Implications for agricultural innovation

In agricultural or rural social research, the nature of power dynamics, social capital, and trust forms will have implications for the development, adaptation, deployment, use, and value obtained by a process of innovation (technical or otherwise) (Small et al., 2016; Taylor and Eberhard, 2020; Turner et al., 2017). These characteristics are also specifically relevant as part of the digitalisation of agriculture agenda via the deployment of tools, sensors and kit that collect data and provide grounds for analysis by actors beyond the farm or land management

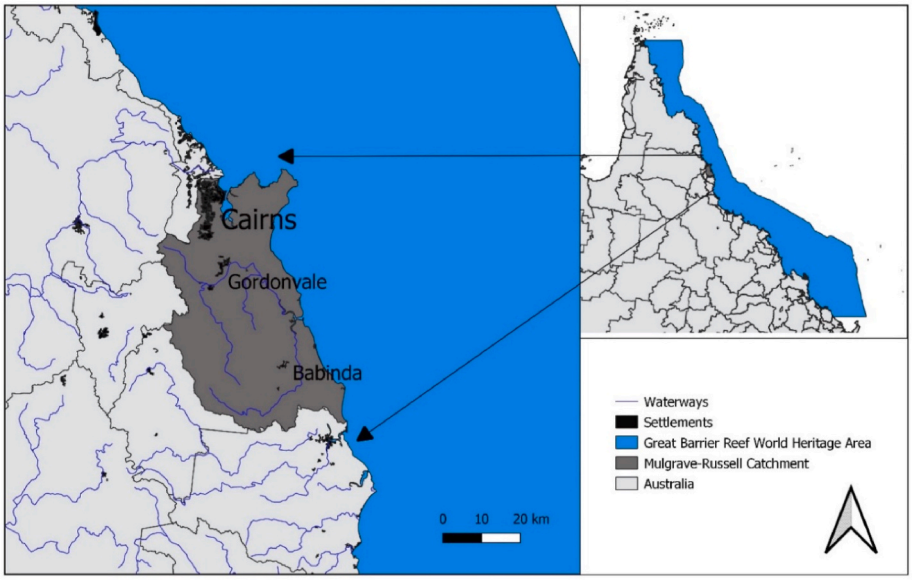

Fig. 2. Map of the case study region (Mulgrave-Russell catchment - source: Fielke et al. (2021)).

Table 2
Aligned forms of social capital stocks and trust flows (adapted from King et al. (2019)).

Number and direction of connections	Social capital stock form	Trust flow form
Multiple horizontal (similar socio-economic status) connections	Bonding social capital – homogenous, close-knit group connections, over time form similar views, can be isolated from wider social exchange	Companion trust – history of interaction over time, informal relationships as often as formal
Few horizontal (similar socio-economic status) connections	Bridging social capital – looser relational connections providing access to resources horizontally between similar social groups	Competence trust – 'swift' trust whereby parties may not know each other but conditional cooperation with other group members leads to perceived competence, can be formal or informal
Few vertical (across socio-economic status) connections	Linking social capital – vertical connections between dissimilar social groups involving boundary spanning to facilitate resource exchange across social hierarchies	Commitment trust – resources may be provided via formal contractual arrangements, such as with governments or funders, formal accountability, and fulfilment of work expectations

scale (Agyekumhene et al., 2018; Jakku et al., 2019; Pink et al., 2018; Wiseman et al., 2019). As such, we developed an analytical framework (Fig. 1) for this research by composing a matrix of:

- Power dynamics – considered at all levels but most likely relating to institutional or organisational characteristics (somewhat separate to the following two characteristics but significantly important in terms of influencing outcomes or lack thereof). Individual and group perceptions of power dynamics influence their interest in becoming involved in processes of change (or forming competing views). Power dynamics determine who can, and does (and how they) engage in project agendas.
- Social capital stocks – considered at any level but most likely relating to group and individual characteristics.
- Trust flows – considered at any level but most likely relating to the characteristics of individual/s interactions with both humans and non-human technologies.

These characteristics help explain the different layers of terminology used throughout this paper (for example governments have ambitions to meet certain environmental targets), individual expectations (for example one might feel they have a right or duty to keep farming), and individual and group practice (of governing, researching, advice-giving, or farming on a day-to-day basis). In the results section we interrogate the primary qualitative data from our case study (capturing two points in time) against this analytical framework. We present references to these social dimensions of power, social capital and trust and explain how they evolve over the life cycle of the collaborative water quality monitoring and digital 'app' development project.

3. Method and case study context

This paper reports on a collaborative and transdisciplinary effort to reduce the environmental impacts of an agricultural industry on freshwater quality adjacent to the World Heritage Area of the Great Barrier Reef (GBR) lagoon. The influence of an increased nutrient load from non-point pollution can result in eutrophication and exacerbate adverse impacts on the GBR (Kroon et al., 2016). This paper builds on research concerning the agricultural knowledge and advice network adjacent to the GBR by providing a longitudinal evaluation of the role of a collaborative farmer-initiated water quality monitoring project in changing perceptions and influencing practices over time (Davis et al., 2021; Fielke et al., 2021).

3.1. Geographic, environmental, and industry problem context

The GBR faces threats from a variety of sources, with one stressor being poor quality freshwater entering the GBR lagoon from terrestrial runoff (Taylor and Eberhard, 2020). Modelling of catchment hydrology and farming system practice has indicated that intensive sugarcane production on catchments directly adjacent the GBR World Heritage is detrimental (Kroon et al., 2016). However, the exact cause of water quality decline remains disputed by the agricultural industry (Patterson et al., 2013, 2015; Schaffelke et al., 2018; Sharma, 2020). This challenge is exacerbated by the nature of invisibility of such an agricultural contribution to declining water quality and it being hard to pinpoint attribution of practice to water quality outcomes. Importantly, the case study catchment region (Fig. 2) drains into the GBR lagoon and has been defined as a 'high management priority for water quality improvement' area (Queensland Government, 2018). A research project was conducted that ***allowed farmers to have greater control over, and build their understanding of, real-time water quality monitoring*** within the Mulgrave-Russell catchment (Davis et al., 2021). This research project was initiated by a group of leading farmers who were directed by the Federal Government via their local CANEGROWERS regional office to steer the project. The research project involved water quality researchers installing automated and high frequency water quality monitoring sensors (taking measurements of nitrate, turbidity and stream height every 60 min). These sensors were adjacent to key locations (including sugarcane farms) identified by the farming community, where practical/accessible and where they could be scientifically relevant in determining what impact land use was having on water quality given explicit weather events (Davis et al., 2021). It was envisaged that the sensed data, once made available to farmers and industry representatives, would result in changes in farmer and industry thinking about how nitrogen moved across the landscape during certain rainfall events and at certain points in time. Originally, this data would be made available to farmers via research presentations tailored to them in a format that they were comfortable with when it was suitable to gather everyone together.

Between the first and second round of interviews (see section 3.3 for more information) a digital tool was designed to provide a near real-time feedback loop via a different research and development project. This digital tool is named 1622WQ (Vilas et al., 2020). Farmers involved with the project could access data as it was measured via an iteratively designed web or mobile application (or 'app') to create further opportunities for changes in thinking that could lead to farm management practice change where and when perceived as necessary.

3.2. Societal, institutional, and political problem context

While the collaborative farmer-initiated project forms one component of the sugarcane farming knowledge and advice network within the case study region, a broader analysis of pre-existing and non-project related perspectives is also important to frame heterogeneity in farmer perceptions (van Grieken et al., 2019). To this end, previous research relevant to the sugarcane industry (Thorburn et al., 2011) and perceptions of agricultural impacts on the GBR more broadly were used to frame the specific social research methodology utilised (Taylor and Eberhard, 2020).

Ongoing resistance to perceived government 'interference' is rife in the Australian agricultural sector and it has been identified that such a hands-off approach to agricultural governance can lead to the ostracization of farming communities (Fielke and Wilson, 2017). For instance, individuals and industry group expectations regarding land management decisions and associated development of regulation can become highly political and contentious (Fielke et al., 2021; Knook et al., 2020).

In fact, in this case study, industry regulations were altered between the first and second round of interviews, and a subsequent senate inquiry took place investigating the nature of such changes, involving input that referenced this research project (Commonwealth of Australia, 2020; Davis et al., 2021). By employing the methodology that follows we probed the views of individuals involved with land management, governance, and relevant research and development processes over time, to build an understanding of how social capital, trust, and power dynamics evolved.

Importantly, such collaborative water quality monitoring projects are increasingly being developed and deployed across GBR catchments, led and funded by various regional and catchment-wide organisations, collectives, and advisory bodies. This research project is seen as a leading example of such an investment, although work such as this paper is needed to highlight both the opportunities and challenges of such an approach to diffuse water quality management in complex institutional and political contexts (Kroon et al., 2016; Taylor and Eberhard, 2020).

3.3. Methodology

Two rounds of qualitative interviews were conducted with the same set of farmers, advisors, and researchers which allowed for change (or lack thereof) over time to be reported. These interviewees were purposively chosen because they were involved with sugarcane farming and/or water quality monitoring efforts in the case study region. There were 19 interviewees in 2018, and subsequently 18 (of the same) interviewees in 2020 (see Table 3). In person (14) and telephone or video call (5) interviews ranged from 24 to 57 min in 2018. All interviews were telephone or video call interviews in 2020 due to the COVID-19 pandemic and ranged from 15 to 51 min. All interviews were transcribed verbatim by a professional transcription organisation. The data were imported to Nvivo for analysis. The dataset captures a combination of farmers (12 then 11[1]), advisors (4) (based in Mulgrave-Russell catchment – Fig. 2) and researchers (4) based in Queensland. The interviewees were recruited via snowballing supported by the lead industry body's (CANEGROWERS) local office – spatially located within the case study region. Six of the farmers were involved with the collaborative water quality monitoring project (in both 2018 and 2020) and six were not (in 2018 and five in 2020). The industry's body provided contact details until we had similar numbers of involved and not involved respondents willing to be interviewed. Perceptions of those farmers 'involved in the water quality project' and those 'not involved' were gathered to provide a more accurate qualitative assessment of the impacts of the research project and 1622WQ 'app' interventions in the case study agricultural knowledge and advice network (Hesse et al., 2019).

Table 3
Case study interviewee codes, roles, additional information of relevance to water quality monitoring (WQ) project, years interviewed.

Interviewee code	Role	Additional information/ relevance	2018	2020
A1	Advisor	Local industry body	X	X
A2	Advisor	Local extension officer	X	X
A3	Advisor	Local extension officer	X	X
A4	Advisor	Industry research organisation	X	X
R1	Researcher	Design	X	X
R2	Researcher	Water quality	X	X
R3	Researcher	Agronomy	X	X
R5	Researcher	Water quality	X	X
IF1	Farmer	Involved in WQ project	X	X
IF2	Farmer	Involved in WQ project	X	X
IF3	Farmer	Involved in WQ project	X	X
IF4	Farmer	Involved in WQ project	X	X
IF5	Farmer	Involved in WQ project	X	X
IF6	Farmer	Involved in WQ project	X	X
NF1	Farmer	Not involved	X	X
NF2	Farmer	Not involved	X	X
NF3	Farmer	Not involved	X	
NF4	Farmer	Not involved	X	X
NF5	Farmer	Not involved	X	X
NF6	Farmer	Not involved	X	X

[1] Two farmers were interviewed together in person on the farm they both managed in 2018, only one of them was spoken to on the phone in 2020.

A three step inductive thematic analysis was conducted as a mechanism to consider the conceptual layers - social capital, trust and power dynamics - that have been found to be critical when assessing innovation and change in rural and agricultural contexts (Fielke and Srinivasan, 2018; King et al., 2019; Turner et al., 2020). This research project provided a case study project to analyse whereby farmers could co-develop the measurement process to determine how and when nitrogen was leaving agricultural land to mitigate the denial of an invisible environmental management issue (Yin, 2014). It was envisaged the progress of the research project, due to scientific engagements/interventions in the agricultural community, would lead to the next stages of acceptance and planning, in terms of what to do about practice based on the water quality monitoring findings. Our thematic analysis worked to capture developments during this process of project development and deployment and each stage of analysis allowed for increasing depth of qualitative understanding to be built.

- The first stage of analysis involved probing primary data to divide into evidence of specific social capital (bonding, bridging, and linking) and trust (competency, commitment and companion) forms.
- The second stage of analysis involved probing primary data to divide into evidence of existing power dynamics and potential alterations/reconfigurations of power dynamics within the case study agricultural knowledge and advice network.
- The final stage of analysis involved looking at the resulting analysis from the previous two stages considering the temporal change (2018 and 2020) and role of the actors (farmers involved with the research project, non-involved farmers, advisors, and researchers).

4. Results

Our analysis is segregated according to the two periods of data capture (2018 and 2020) and the dominant characteristics of power, social capital, and trust. This is presented below in sections 4.1 and 4.2. Next, a summary of the results is presented in the form of a qualitative narrative (Box 1) and a diagrammatic representation (Fig. 3) in section 4.3. More information regarding the in-depth coding structure and a more extensive range of the quotations relating to the dominant characteristics can be found in the 'Appendix' for both 2018 (Table A1) and 2020 (Table A2).

4.1. Benchmarking power, social capital, and trust – 2018 analysis

In a quote indicative of latent power dynamic perceptions and a lack of working together in 2018, one non-involved farmer provided this statement regarding the adversarial nature of government and media reporting on farming practice:

> You've got to know … to point the finger at someone, if you go to court, you've got to have proof … to come out in the paper [the Government] and say the cane farmers are throwing fertiliser down the drain. (NF4 2018)

This quote speaks to the benchmark 'perspective' of existing water quality modelling in the farming community when forms of policy and governance to date are considered. This quote highlights the science-policy-industry tension that we expand on in the remainder of this

section.

4.1.1. Power dynamics: not yet 'working together'

In describing the situation in 2018, one involved farmer notes the legacy challenge of engaging constituents with policy that affects their practice in politically fraught contexts, reinforcing a lack of power to 'work together' in this domain. Their approach to initiating the project, especially in maintaining privacy of the data and information within the farming community, - is justified to them by their previous experiences:

> I think they're standoffish, a lot of the growers, because over the years … they've been used as a political football … politicians see the Great Barrier Reef as a great election tool … We had to have control of it [the data] … we don't want a headline in the Cairns Post overnight … because then we'll just lose trust of growers because if we don't have trust between each other … that's the underpinning thing of a project. (IF2 2018)

Importantly, there is recognition – particularly from involved farmers, advisors, and researchers of the need to 'work together' into the future – to shift the power dynamic from one of government having power 'over' the industry, to one recognising the need for cooperation, synergy and mutual dependency. One advisor explains their motivation for getting involved in such a collaborative approach:

> I'm personally interested in breaking down the barriers a bit between the water quality science and growers and the cane industry. Demystifying the science and building that trust. I think doing monitoring together with growers is probably the best way to do that. (A4 2018)

In 2018, researchers involved in the research project were beginning to roll out water quality monitoring stations across the catchment and while the tension concerning the latent power dynamics were recognised, so was the need to build bridges across groups of individuals.

4.1.2. Social capital stocks: Need to build bridges

In thinking about deploying water quality monitoring equipment on-farm, a non-involved farmer didn't see the problem with the equipment, rather the potential use of data was of concern unless it told a 'good story'. This farmer also mentions that their colleagues would likely do something about losing nitrogen, alluding to the proposition that these technologies *could* help develop a clearer bridging of scientific and farming community world views:

> There's probably a reasonable percentage … that would be open to having that type of thing on farm … But I'm not sure that they want to share too much data at present unless it's a really good story. But I think probably the vast majority would want to know if they're losing their nitrogen and if they are, they will do something about it. (NF1 2018)

One of the advisors explained how the bridging social capital built through these efforts could be anticipated to alter the farming culture and bonds shared within the region, with involved farmers becoming leaders that share information developed from the data and engage other farmers with water quality science. Ultimately, this perception was framed as a mechanism to minimise the ongoing resourcing across 'every small' GBR catchment:

> You would hope that some of these growers become champions or conduits for sharing that information and building that trust rather than needing to spend hundreds of thousands of dollars on every small catchment. (A4 2018)

Technological developments in near real-time water quality monitoring devices were presented via scientist engagement at traditional 'shed meetings' and through a nascent digital application (1622WQ). Through these processes a connection was made (or bridges crossed) between the complementary aims of the project efforts across farmers, governments, and researchers who could use their success stories to have a real impact across the GBR catchments.

4.1.3. Trust flows: Starting to prove competence and show commitment

The only mechanism for building the bridging social capital needed to engage industry and scientific worlds in a cooperative research endeavour is through the development of competence trust. Competence trust provides a basis for groups to feel as though involvement of another individual or group (whether that be researcher/s or advisor/s or policy maker/s) poses minimal risk to the dynamics of the existing group. It was promising that the initiation of the research project, ongoing farmer ownership, and willingness of participants to engage in the research process via trusted intermediation (bridge building) was directed from government. This process allowed for an industry-initiated research project that could utilise existing advice and research networks to increase the likely reach of impact as a result. A farmer not involved directly with the project highlights the role of a trusted advisor in laying the foundation for amicable negotiations:

> They [scientist/s] come around one day with our CANEGROWERS representative and a couple of other blokes and they asked, would you mind if we put it [water quality monitoring station] on there and I asked what it's all about … I said go for it. I've got nothing to hide. (NF6 2018)

An involved farmer explains the logic of the need to maintain and build on this competence trust over time to show an 'outsider' is committed:

> If you're going to take the growers [with you] it's got to be credible. If you just turn up with something and say 'here it is' you won't get credibility. (IF3 2018)

This 2018 analysis presented the state of power dynamics, social capital, and trust as the research project effort ramped up. The key points to note are, firstly, that pre-existing (perceptions of) power dynamics and the terms of the engagement will shape the attitudes with which different individuals and groups will approach such a project. Secondly, the building of bridging social capital and competence trust through dialogue – as a precursor to the development of commitment trust – can be utilised to intervene when (perceptions of) power dynamics may not be favourable. In support of this second proposition, a researcher stated:

> The more you talk to farmers the more they're going to trust you. The more they see you the more they're going to trust you. (R3 2018)

4.2. Evolution in power, social capital, and trust – 2020 analysis

The passing of 18 months between late 2018 and mid 2020 included much development regarding the operation of the research project and the 1622WQ 'app' development. These social and technological developments both influenced and were influenced by changes in power dynamics, social capital and trust amongst the individuals and groups studied here. An advisor summarises the strategy behind the approach utilised during the project, highlighting the need to temper fears farmers would be 'working for' government:

> It would be terrible to have to bring in some of the other government agencies, because the trust would never be there … You want to create the relationship between that landholder and the ownership of those results. They have to take ownership of the results. If you're not a stakeholder, you can't take ownership of the results. You don't bloody own them. It's nothing to do with you really. I think keeping the government agencies out of it … you try to keep them out of it (A1 2020)

4.2.1. Power dynamics: Working separately, working for, and encouraging working together

During the time that passed there were alterations to the State regulations making it a responsibility of farmers to keep records, comply with minimum agricultural standards and have a nitrogen budget from 2021 onward (Queensland Government, 2020). These regulatory alterations caused farmers to be distracted and more antagonistic. One involved farmer explained the struggle to move from a perception of 'working for' government as a barrier to cooperatively 'working with' government and researchers:

> Of course, all farmers should be involved in water quality and talk about it and everything, but that doesn't happen as much because some farmers are just pulling back because of the way the Queensland Government's gone on with regulation [referring to recent regulation changes]. (IF5 2020)

Similarly, the onus of responsibility to undertake such frequent water quality monitoring projects – from the perspective of one researcher – was one that the industry (and other local bodies) themselves needed to take on, highlighting discrepancies in the expectations of different groups of interviewees:

> I don't think it's the government's responsibility to then roll this out across the state. I think that's where farmers, industry bodies, councils, those kinds of things need to start to step up and do a similar concept. So … get proof of concept out, get some standard operating procedures, get some benchmarks, and then make that very available and say, this is what we recommend. (R4 2020)

Such differences in opinion regarding the power imposed on the farming community resulted in fear of what different groups will do with information and exacerbated a perception that 'working separately' – government staying out of farmers' business – is the best way forward. As one involved farmer explains:

> The growers aren't frightened of the true information … but if it gets in the wrong hands, it could be misinterpreted … We might be able to deal with it [data sharing arrangements] somehow if we can get them to sign some declaration or something. That if they've got concerns, they come back to [the collaborative project farmers and scientists] and not go to the media and all that stuff. That is our concern … We're working towards improvements or getting the facts right. (IF6 2020)

These arguably unshifting power dynamics contrast with the micro-level, or individual and group project subtleties. Because of the project working to air concerns, there was recognition from both involved and non-involved farmers and researchers that these different groups of stakeholders need to find a way to 'open' access to the data, information, and knowledge being developed within the project. An involved farmer highlights benefits can be associated with openness:

> It's that elephant in the room. When do you stop being a closed shop? That's the big question. There's going to be a time when you're going to have to open it up. There's risk involved, but there's reward, as well. It's a hard question to answer and I'm not willing to put my neck out because someone else will chop it off for me … People have got to think about it without thinking the red's [government is] under the bed. That's going to be the thing. They've got to have their conversation and weigh it up, not just go on emotion. (IF2 2020)

Finally, a researcher explains why leading farmers need to balance progress with representation of farming communities:

> They've [leading farmers] got to be seen to support the industry. I think a lot of them are smart enough to know that they've also got to be seen to be taking the more environmentally responsible line at a lot of levels. So, there is always that tension for them between the different stakeholders they've got at some levels. (R2 2020)

4.2.2. Social capital stocks: Exploring new connections

It is critical to recognise and encourage the latent expressions of different forms of social capital and utilise them to align with an agenda to create impact within a community of bonded groups. Initial planning of the collaborative water quality project, and the generous allowance of time to slowly influence perspectives was crucial to receiving any buy-in from farmers at all. The linking social capital that provided resources to create the space for this project was important in building such a foundation:

> No one has denigrated [this research project]. They've all said, well you know, it's probably a better way to do this than just having a scientist walk into a room and the politicians getting there and everyone believes that it's just a political statement or something. (IF3 2020)

A researcher highlights the need to build links across different social groups into the future:

> That narrative is now going to start to change, and we need everybody, whether it be policy people, scientists, agro-advice people, companies like Bayer, all saying that same kind of stuff. With greater information, greater data, we can turn it into more knowledge, and with greater knowledge we can benefit whatever industry. (R4 2020)

For linking social capital to have positive outcomes, resources obtained need to be leveraged to build productive bridging social capital. An involved farmer explains how initiatives like this research project aim to build the bridges between science and industry to collaborate, which forms the base from which bonding social capital within farming and scientist groups can be developed:

> I think that as long as the academic field or science field incorporates the farmers in this, I think [farmers] they're open. I think as long as there's collaboration between the farmers and the science side of it, that's not a problem. (IF5 2020)

There was evidence that investment in this collaborative project (at least in part) had begun to alter farming community social dynamics. Reports from an advisor highlights such development has involved farmers leading the broader farming community to recognise the need for improved fertiliser management practices:

> The people [farmers] that we've been working with, I feel like the way they view themselves has probably changed a bit. Like they see themselves as being informed and wanting to do the right thing and they'll look at other growers and be like, 'oh come on, just get with the program' … They feel proud so the way they view themselves is that we're people who do the right thing. We're quite progressive people and we wouldn't be wanting to over apply a fertiliser anyway. (A4 2020)

This evolution in social capital is examined further when considering changes in flows of trust across the different stakeholders and groups involved.

4.2.3. Trust flows: It's all about trust in others' competence

The analysis thus far has highlighted the implications of previous activity (or lack of activity) on the level and form of trust (of lack thereof) held by case study stakeholders and their groups. This section reflects developments regarding trust of involved stakeholders, which is beginning to influence those farmers who were not directly involved. An advisor highlights the implications of this project (over time) and how the approach researchers have taken has built competence trust regarding their scientific practice:

> I think it's more and more accepted, it [the collaborative project and water quality monitoring] has been going for a few years. Most of them [farmers] are aware of who's getting what data and what's happening there. That … they're not trying to catch someone out, or something extreme, reporting to the government all this data, or something crazy. (A3 2020)

One non-involved farmer goes further to highlight how their trust in the scientific competence of the project team members and the outputs they provide – both in person and via technology – tell farmers what they shouldn't be doing:

> It's [the research project outputs] telling farmers that are putting their fertiliser on top of the ground just before a rain event that they cause the problem … it's getting through and I think the softer approach is better than the big stick approach [for example new forms of regulation], because the big stick approach all it does is get farmers to get their back up. (NF5 2020)

The process of getting to a place of trust in scientist competence via collaborative means and a commitment (via resources and ongoing engagement) to the industry is described by an involved farmer:

> A lot of the stuff [scientific modelling] that was coming out before there was no collaboration between farmers and scientists and all that sort of stuff and probably the trust [about whether] the information was correct was a little bit to be desired. Whereas with this [collaborative project], because we're working together and you see the information, well you can start to believe what you're seeing and then that gives you some scope of what you're going to do in the future … That information gives us the opportunity, gives farmers and even fertiliser companies [hope] there is something there that they can work on, right? I don't know whether slow-release fertilisers and all this sort of stuff, but we have identified a distinct problem, if you can put it that way. Through what we've been through [with the collaborative project], we have identified there's an issue there, right, with that first flush. (IF4 2020)

Another involved farmer puts it more simply:

> They'll [farmers] always question that [modelling], where now, they can't really question it [near real-time sensed data]. It's actual sensing data, so I think it has moved on. (IF2 2020)

A researcher describes the change in their approach that was required, compared with traditional science-led projects, to build the competence trust that enables a change in the companion trust flows and influences strong bonds within industry groups:

> Just being aware that it takes time and you've got to tread carefully for a while … you're dealing with people with a different perspective on things, you're not going to change their minds in six months or with the first bit of data that you show them, [but] eventually you will find a lot more common ground with them … Just being open and transparent too … When we've had something weird fall out of data or one of the sensors … I've put it up on a PowerPoint or I'll send it out in an email and point to it, this isn't real … I think sometimes if you admit when things haven't gone right, your mistakes, it just helps them trust you. They'll believe you. There's more credibility when they know that you don't try and bullshit your way through the unexpected things. (R2 2020)

The following section briefly summarises the analysis undertaken *across* the 2018 and 2020 qualitative data.

4.3. Summary of developments over time in narrative and visual form

Box 1 presents an extended narrative from a water quality researcher regarding a rather informal interaction with an involved farmer in which they worked together to figure out where the 'problem' (spikes in nitrogen concentration) was coming from via experimentation (R2,

Box 1
In-depth analysis (bold text) of narrative from researcher (R2, 2020) to highlight the analytical value of the framework to step through social progress relating to the socio-technical intervention.

Social capital stocks: Competence trust was leveraged to create an opportunity to further develop bridging social capital

One of the growers rang me one day and said, 'oh [scientist] there's a spike going down this drain', which is next to his farm … He said to me, 'if we have a spike come through you could sort of come up and see if we can work out where it's coming from?' … About three days later [it rained] … He rang me and said, 'oh what are we going to do about it, are you going to come up and have a look?' I had to get up early the next morning, drive up there with him …

Power dynamics: The power of technology and expertise combined to expose the implications of farming practice

With this one site there's two drains that feed into it just upstream, and you can sort of take a bucket from one and a bucket from another and see which one's responsible for the major part, this is what we found anyway, that one drain was particularly contributing to the concentrations that we were seeing at that time. So, we drove around for about 3 h collecting buckets of water from different parts of the drain and eventually I isolated specific paddocks where this was coming from … We eventually nailed it … It's exciting in some ways where it sort of underlines the power of sensor technologies and things, where growers can see what's happening in real-time …

Trust flows: Turning a trusted interaction into a bridge to social influence by working together with curiosity

There's literally water pouring off this guy's paddock that I ended up getting a bucket off and just going and putting that into the sensor. Yeah, it jumped out as probably what was causing most of this spike. The grower himself was interested, he was like, 'oh right well now that we know where it's coming from we've got to work out what caused it and what we can do about it' … He [farmer] was quite interested in that and was going to go and have a 'chat' to the grower about it [to figure out what caused the spike]. He kept me up to speed on things about that and said, oh look we [would like to] do this again another time and we'll get the growers to come along … that was probably one of the last big flushes that we had. It doesn't go forever, it gets exhausted eventually, those nitrate spikes …

Summing up the findings of this paper

I think if you go about it the right way, and you've got that [**competence**] trust and [**bridging social capital**] rapport with them, I think after a few years [**of working together**] – and they're familiar with it, and what happens, and what it looks like and what it means – I don't think they're as adversarial or intimidated by it as they probably were initially.

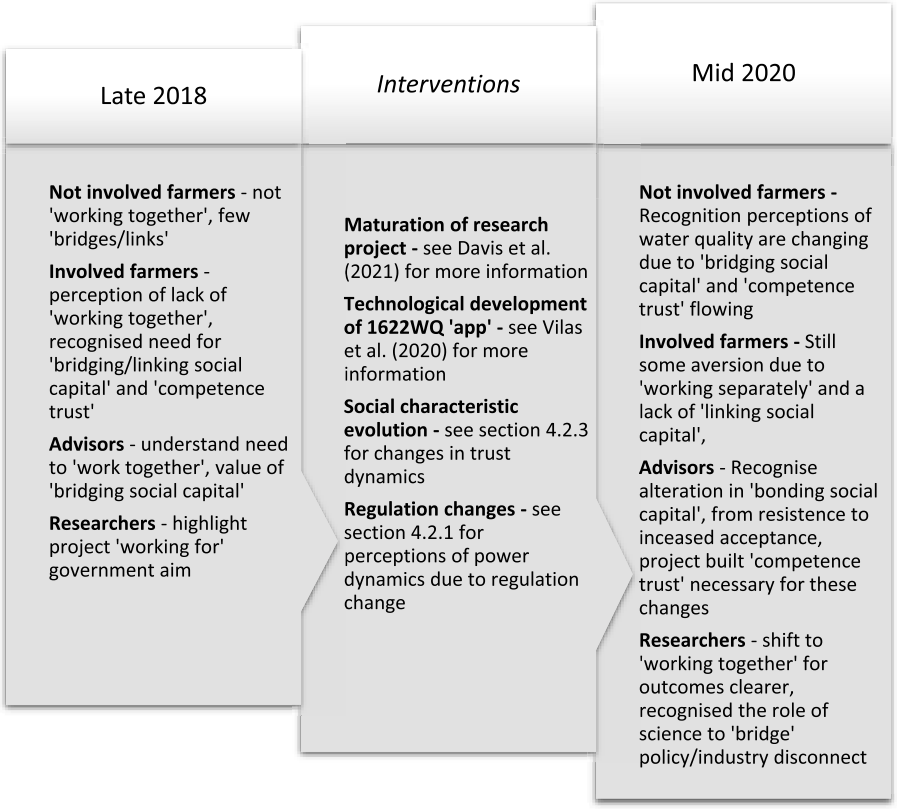

Fig. 3. Analysis of the changing social dimensions during the farmer-initiated collaborative water quality monitoring project over time.

2020). Due to previous deep engagement and competence trust, collaborative use of the sensor technology, and the resulting expression of working together to build bridging social capital, there was an opportunity for learning that could then further influence others in the farming community. This narrative provides a summary of the analysis that is shown visually in Fig. 3. Fig. 3 presents the core evolution of the social dimensions captured against our analytical framework as part of this project over time, considering the socio-technical research and development interventions that occurred.

5. Discussion

Here, we report on relevant implications of our analysis to address the three research questions relating to power dynamics, social capital, and trust. Taken together, in this case study, analysing social dimensions (in the form of social capital stocks, trust flows and power dynamics) throughout this transdisciplinary research project helped to plan for and intervene over time to increase the likelihood of achieving impact from voluntary changes in farmer behaviour. We suggest the outputs of such an approach could help achieve the softer institutional progression that many improved land management practice initiatives seek in light-touch regulatory environments.

5.1. Linking individual and institutional trust through power redistribution

In this section we provide an answer to the first research question:

What are the power dynamics (and changes to those dynamics) that need to be considered when aligning terrestrial runoff pollution challenges with agricultural fertiliser management practice?

We found that the approach to this project collaboration and industry case study began by reversing existing power 'over' farmers by giving a select group of farmers and industry representatives the mandate to initiate the research project. Such an approach was critical in terms of addressing industry perceptions of previous aggrievances whereby the farming community felt they had ownership of the project development, could have input into who had access to the data feeds, and re-oriented their perceptions. This finding explicitly supports claims made by Turner et al. (2020, p. 159) whereby the role of 'actors mobilising resources to transform power relations among platform actors' was found to be of importance in changing power dynamics. We show, in support of existing literature examining how and why 'working separately' from 'government' and 'science' may be optimal for an industry stakeholder/s given existing systemic perspectives, that it is still possible to move toward a model whereby 'working together' is prioritised (Berkes, 2009; Clapp et al., 2018; McCampbell et al., 2018).

Such power redistribution can have negative outcomes, and there is a question of 'when and to whom' data and information access is given. Similarly, while the time taken to achieve outcomes may have been frustrating for some, without such farmer-ownership the existing perceptions of scientific and governance institutions would have hampered project engagement and relevance even more. As such, we build on previous work (Avelino and Wittmayer, 2016; Dolinska and d'Aquino, 2016; Schmidt-Thomé and Mäntysalo, 2014; Turner et al., 2020), to support the notion that providing institutional mechanisms to empower those actors that feel disempowered allows for progress in reducing antagonistic power relations and creating space for exploration of alternative arrangements.

As research in New Zealand has uncovered, providing the opportunity for actors to learn 'their' way can have much longer-lasting success in largely voluntary agricultural practice change scenarios by providing exposure to the agendas of other political or industry forces that can be aligned with (Knook et al., 2020). These forces can then be joined to solidify benefits of the collaboration in the longer term – for example involved farmer recognition by 2020 that there will come a time when they need to '*open it [data and information created within the research*

project] up' beyond the farming community to prove that the research is having a real-world impact.

5.2. Considering social capital assets and liabilities

Our analysis also provides evidence across two points in time, 18 months apart, to answer the second research question:

How do stocks of social capital and flows of trust influence farmer engagement with a specific diffuse water quality monitoring project over time?

The process of initiating the research project with a group of farmers and their industry body, in collaboration with researchers from scientific institutions, did not mean that positive results were guaranteed to manifest. Significant effort has been expended previously on projects that have not resulted in meaningful alteration of the social capital stocks or trust flows that were needed to achieve (at least some) socio-technical project goals (Higgins et al., 2017; Jakku et al., 2019; King et al., 2019; Mutenje et al., 2016).

Practically, we found that existing stock(s) of social capital will determine if links can be made to higher level improved land management practice agendas and the pace at which such agendas can be pursued (Laplane and Mazzucato, 2020). For example, in this case the bonding social capital present at the outset of the research project provided the impetus for industry to initiate the project. Linking capital was leveraged to create the project opportunity via funding and support through bridges to researchers tasked with deploying the water quality monitoring equipment. Such occurrence at the group and network levels elaborates on the dynamic interplay of individual, group and material (i.e. technology and regulation) characteristics, which Inman et al. (2018) have already found critical. Existing stock(s) of social capital influenced the potential to build bridges into other social groups (various scientists, advisors, governance actors, farmers) to increase the collective imperative on the individual farmers to adopt improved land management practices (Dowd et al., 2014; McKee et al., 2015; Steffen et al., 2015; Velu, 2015). Linking social capital is derived from flows of commitment and competence trust. A question remains in this case study as to what happens now that the research project has run its course as to whether the linking capital has been strengthened (or weakened) to the extent that the water quality monitoring efforts may continue (or cease). To align with higher level agendas, actors must build or have trust that those with the power to influence them are competent in their practice and have some form of commitment to the wellbeing/practices/outputs of those in the industry (Cofré-Bravo et al., 2019; Klerkx and Proctor, 2013).

Finally, and relating more to the research stakeholders who do not tend to be the obvious focus of such research, the evolving competence trust and bridging social capital between research management and researchers who need to engage to achieve impact will require negotiation into the future. As others have recognised, researcher engagement with collaborative industry-initiated projects is not readily rewarded in academic promotion or scientific circles of influence (Botha et al., 2014; Harris and Lyon, 2013; McKee et al., 2015; Small et al., 2015). When a researcher also answers to industry actors who do not share scientific-based performance indicators, the conduct of research is harder to undertake in a timely fashion (and it would defeat the purpose of two-way learning to try to rush it). Thus, this way of practicing science takes more engagement energy, and publishing the outputs can be challenging.

5.3. Considering social dimensions of collaborative farmer-initiated projects

The final research question to answer is:

What are the implications of considering multiple social characteristics to improve outcomes from collaborative projects within agricultural knowledge and advice systems?

Our analysis shows that without the project interventions to proactively address, and report on, the latent power dynamics, social capital and trust flows, it would have been challenging to develop the level of buy-in achieved from different actors in this agricultural knowledge and advice network. Testing this answer across cases would further legitimise our findings, though this work does already borrow from lessons that exist in a vast literature (Botha et al., 2017; King et al., 2019; Turner et al., 2017, 2020). Most importantly, in this case as found in other research, higher-level government and scientific agendas are unlikely to be achieved in short time frames with such a voluntary approach; however, such an approach is far more palatable in socio-politically contentious conditions (Nettle et al., 2018; Schmidt-Thomé and Mäntysalo, 2014; Thompson et al., 2017; Turner et al., 2020).

Individually, the lack of commitment farmers perceive government to have for their industry generally, and specifically their resistance in response to targeted regulatory changes, result in a view that government and industry are best served 'working separately'. Such a finding is not novel and supports the empirical work of Small et al. (2016) in elucidating the relevance of behavioural variables to the adoption of land management practices. Here, we provide qualitative nuance by adding that water quality monitoring projects can provide a mechanism through which individual values and dominant narratives of power can begin to be altered. Building bridging social capital provided an opportunity for competence trust to be validated to the point where the researcher-farmer relationship began to alter the companion trust of farmers. This alteration is like the process reported by Srinivasan and Elley (2018), whereby competence trust in researchers was built via ongoing validation of experiential knowledge of the farming community and such engagement was also a new capability for the research project team in this case. Heavy-handed regulation in such a case would only serve to increase antagonistic relationships further, creating more conflict across well-organised social groups who feel powerless, building further resistance to change voluntarily by reinforcing their opposition wherever possible (Sabatier et al., 1987). Critically, such an approach would undo the goodwill created by talented and energetic individuals that have advocated for change by co-developing scientifically rigorous findings (Davis et al., 2021; Vilas et al., 2020). Even worse, reverting to a competitive approach would prevent the development of a pathway toward societal and industry evolution that accepts as important a process of lifelong environmental improvement in land management practices. As one involved farmer aptly puts it:

[The collaborative project] it's planting the seed of knowledge, of understanding. Okay, you'll get the old bloke, he might look at it and go, 'it's all shit'. But he's not going to be around in five years, right? But the one who's going back [to the 1622WQ 'app'] is the progressive farmer, and they're going to be the ones to take all that land over. So, you're setting up the future. (IF2 2020).

6. Conclusion and limitations

There are obvious limits to the scope of this in-depth qualitative study over two points in time, it is not statistically generalisable over a large population, or representative of other catchments within the greater GBR region (see Fig. 2). Alternate case study projects, groups, individuals, as well as the varying external influences (and perceptions of them) that arise over time, may involve the evolution of very different interactions of power dynamics, social capital, and trust. Further, conducting such qualitative research results in 'perceptions' of power of others and relational characteristics that may be different to 'actual' reactions. We recognise that such a methodology is highly subjective and influenced by the relationships (or lack thereof) between social researchers and research subjects and open to the bias of the researchers themselves – an inevitable flaw when conducting such work that is widely publicised (Beers and Bots, 2009; Flyvbjerg, 2006; Greene et al., 2005; Mielke et al., 2017; Onwuegbuzie and Leech, 2006).

Importantly, however, the convergence of social concepts presented

here – social capital, trust, and power in their different forms, across GBR catchments and more generally when seeking improved land management practice outcomes, will determine the level of acceptance of options for voluntary behaviour change. The application of such multifaceted social dimension conceptual consideration (see Fig. 3) is an asset that can be drawn upon from the very start of subsequent initiatives to guide the most appropriate interventions to pursue given the contentiousness of the 'problem', the resources available and the practice change sought. This research adds methodological depth to a largely quantitative and 'hard' science embedded case study 'problem'; diversity that many have called for as societal challenges, and the research for impact that attempts to address them, increase in complexity (Hesse et al., 2019; Stone-Jovicich et al., 2019).

Here we found that *analysing social dimensions (in the form of social capital stocks, trust flows and power dynamics) throughout this transdisciplinary research project helped to plan for and intervene over time to increase the likelihood of achieving impact from voluntary changes in farmer behaviour*. Such findings are relevant to any problem where light-touch regulatory approaches necessarily involve collaboration with scientific and industry stakeholders and seek some form of improved land management practice. More broadly, as sustainability transitions requiring alterations in individual and group behaviour are sought, our analytical framework (Fig. 1) can be deployed alongside those such as the multi-level perspective to assess initial willingness of knowledge and advisory network actors to engage with such a process (Avelino, 2011; Geels, 2010, 2011; Wittmayer and Schäpke, 2014). Potential intervention and resource requirements may then become clearer, this knowledge could then help overcome social barriers, and increase the likelihood of successful sustainability outcomes – both land management related and otherwise (Avelino and Wittmayer, 2016).

Credit statement

SF – Conceptualisation; Data curation; Formal analysis; Methodology; Project administration; Writing – original draft; Writing – review & editing. BT – Conceptualisation; Data curation; Formal analysis; Methodology; Funding acquisition; Supervision; Writing – review & editing. AC – Funding acquisition; Project administration; Writing - original draft; Writing - review & editing. EJ - Funding acquisition; Methodology; Project administration; Writing – review & editing. AMD - Funding acquisition; Project administration; Writing – review & editing. PJT - Funding acquisition; Project administration; Writing – review & editing. AJW - Project administration; Validation; Writing – review & editing. JCRS - Writing – review & editing.

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